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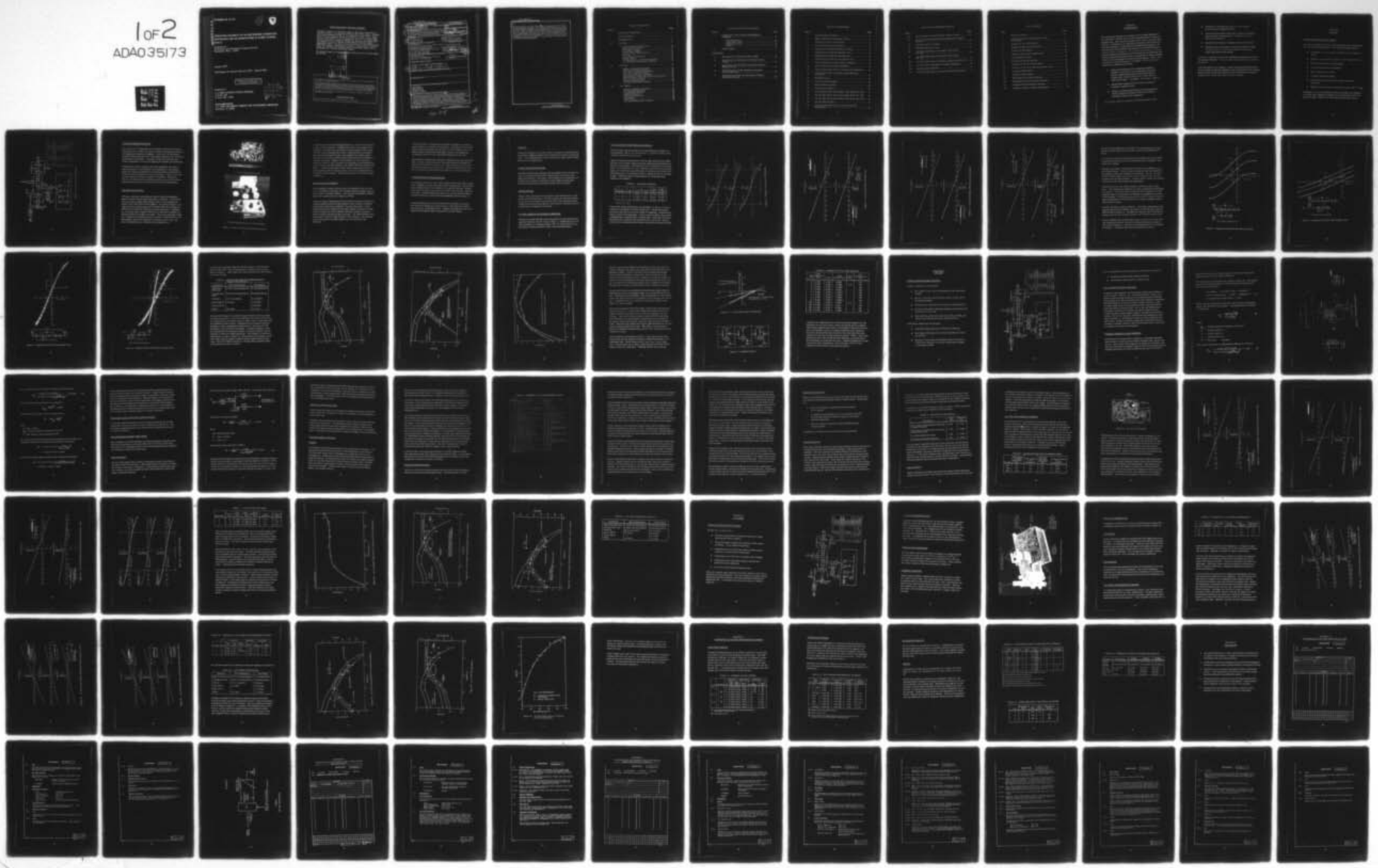

USAAMRDL-TR-76-42

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PRODUCTION SUITABILITY OF AN ELECTROFORM CONDUCTIVE WAX PROCESS FOR THE MANUFACTURE OF FLUIDIC SYSTEMS, PHASE II

Honeywell Inc.
Government and Aeronautical Products Division
Minneapolis, Minn. 55413

January 1977

Final Report for Period February 1975 - March 1976

Approved for public release;
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Prepared for

U. S. ARMY AVIATION SYSTEMS COMMAND
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EUSTIS DIRECTORATE POSITION STATEMENT

This report is Phase II of a three-phase program to determine and demonstrate the production suitability of the Electroform Conductive Wax (ECW) process in conjunction with existing conventional processes for the manufacture of fluidic systems. During Phase II, the pilot production line that was defined during Phase I of this program was set up and checked out by the fabrication and test of nine hydrofluidic systems. The pilot production line included all manufacturing, inspection, and assembly equipment necessary to build the integrated amplifier-manifold Hydrofluidic Stability Augmentation Systems. The data from the pilot production line was analyzed and the ECW process modified as determined to be necessary. During Phase III, a small production run consisting of 20 Hydrofluidic Stability Augmentation Systems will be accomplished and a Technical Data Package prepared.

Mr. George W. Fosdick of the Systems Support Division served as the project engineer for this effort.

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REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
18 1. REPORT NUMBER 19 USAAMRDL-TR-76-42	2. GOVT ACCESSION NO.
	3. RECIPIENT'S CATALOG NUMBER 9
6 4. TITLE (and Subtitle) PRODUCTION SUITABILITY OF AN ELECTROFORM CONDUCTIVE WAX PROCESS FOR THE MANUFACTURE OF FLUIDIC SYSTEMS, Phase II.	5. TYPE OF REPORT & PERIOD COVERED FINAL REP[redacted]T, Febr[redacted]y 1[redacted]75—Mar[redacted] 1[redacted]76
	6. PERFORMING ORG. REPORT NUMBER 2760-47021
10 7. AUTHOR(s) Walter/Posingies	15 8. CONTRACT OR GRANT NUMBER(s) DAAJ02-74-C-0012
9. PERFORMING ORGANIZATION NAME AND ADDRESS Honeywell Inc. Government and Aeronautical Products Division Minneapolis, Minnesota 55413	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 98L(1)692000, 74004
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Aviation Systems Command P.O. Box 209, Main Office St. Louis, Missouri 63166	11 12. REPORT DATE Janu[redacted]y 1[redacted]77
	12 13. NUMBER OF PAGES 117 118p.
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Eustis Directorate U.S. Army Air Mobility R&D Laboratory Fort Eustis, Virginia 23604	15. SECURITY CLASS. (of this report) Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

14 GAPD-2760-47021

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Hydrofluidics
Electroforming
Conductive Wax
Production Process

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This document presents the results of Phase II of a three-phase program to determine and demonstrate the production suitability of the Electroform Conductive Wax process in conjunction with conventional production processes for the manufacture of fluidic systems. During Phase I, an integrated amplifier-manifold hydrofluidic stability augmentation system using the Electroform Conductive Wax process was successfully designed, fabricated, and qualification tested, and a pilot production line using the Electroform

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Conductive Wax process was defined. The pilot production line includes all manufacturing, inspection, and assembly equipment necessary to produce the integrated amplifier-manifold hydrofluidic stability augmentation systems. Phase II included the setup and checkout of the pilot production line. Three groups of three systems each were fabricated and tested. Circuit configuration and production processes were changed as a result of the analysis of each group of components. In Phase III, a small "proof" production run will be accomplished, component quality determined, and a technical data package prepared.

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SECTION I

INTRODUCTION

Most conventional production techniques are not readily adaptable to the manufacture of fluidic devices with small passageways, intricate configurations, close-tolerance requirements, and the need for sealed circuits. Consequently, the Electroform Conductive Wax (ECW) process was developed. Through various developmental programs, the ECW process has demonstrated the potential to accurately fabricate leakproof fluidic components. The object of this program is to determine the production suitability of the ECW process in conjunction with existing conventional processes for the manufacture of fluidic systems. This is a 34-month program divided into three phases. Phase I was the subject of a previous report, USAAMRDL-TR-75-49, and consisted of the following major tasks:

- Design and development of an integrated amplifier-manifold circuit for use in the hydrofluidic yaw-axis stability augmentation system (SAS), which was developed under Contract DAAJ02-72-C-0051 with the Eustis Directorate, USAAMRDL, Fort Eustis, Virginia.
- Qualification testing of the SAS with the integrated amplifier-manifold circuit.
- Design of a pilot production line for the fabrication of fluidic components using the ECW process and for functional testing of the components.

This report, Phase II, consists of the following major tasks:

- Manufacture, assembly and checkout of the complete production line designed in Phase I.

- Fabrication and testing of three lots of system components using the Phase I production line. Each lot consists of three sets of hardware.

- Assembly and testing of a complete system from each lot.

- Analysis of the test results of each lot to modify the design, the ECW process, or process equipment, if necessary, before fabrication of the next lot.

Appendixes A through D present the established component and electroforming specifications. The final system specification is presented in Appendix E.

In the final phase of the program, twenty systems will be fabricated in four lots using the process finalized in this second phase of the program. Results will be statistically analyzed, and a technical data package defining the SAS and the ECW process will be compiled.

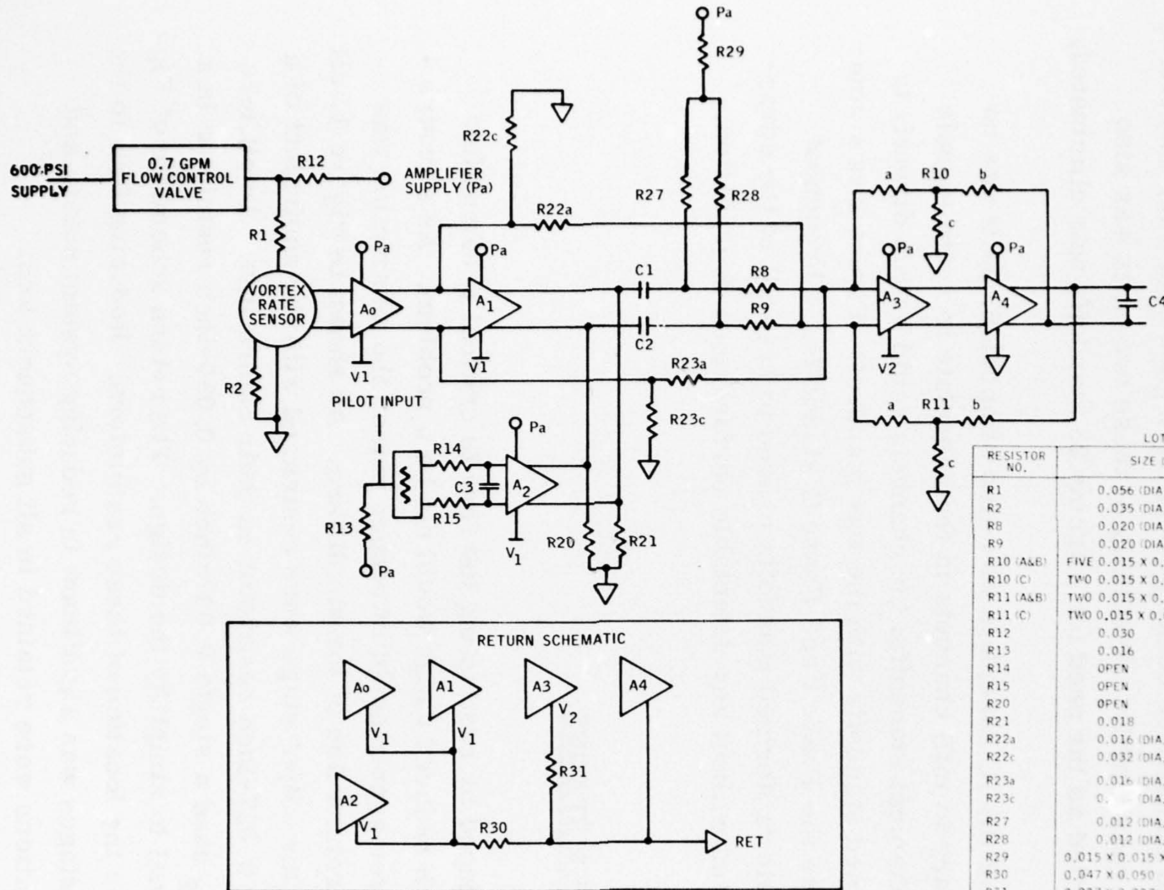
SECTION II
LOT ONE

SYSTEM CONFIGURATION SUMMARY

All recommendations from Phase I of this program were incorporated into the first preproduction lot. These recommendations were to:

- Incorporate the electroformed standoffs onto the integrated circuit
- Operate the preamplifier stages at a lower supply pressure
- Eliminate feedback on the preamplifier
- Use a four-port rate sensor pickoff
- Pin the PID link to the shaft
- Use linear high-pass bellows
- Install the system return on the bottom cover of the rate sensor
- Modify the external bolt on resistors to accept -005 "O" rings

In addition, the Lot one integrated circuit (IC) design was modified to use a high input impedance amplifier as the second stage of the rate sensor cascade. Figure 1 is a schematic of the Lot one system.



LOT ONE RESISTORS

RESISTOR NO.	SIZE (IN.)	CONFIGURATION
R1	0.056 (DIA.)	DRILLED IN HOUSING
R2	0.035 (DIA.)	REPLACEABLE
R8	0.020 (DIA.)	REPLACEABLE
R9	0.020 (DIA.)	REPLACEABLE
R10 (A&B)	FIVE 0.015 x 0.015 IN SERIES	BOLT ON ELECTROFORMED RESISTOR ASSEMBLY
R10 (C)	TWO 0.015 x 0.015 IN SERIES	
R11 (A&B)	TWO 0.015 x 0.015 IN SERIES	BOLT ON ELECTROFORMED RESISTOR ASSEMBLY
R11 (C)	TWO 0.015 x 0.015 IN SERIES	
R12	0.030	REPLACEABLE
R13	0.016	REPLACEABLE
R14	OPEN	REPLACEABLE
R15	OPEN	REPLACEABLE
R20	OPEN	REPLACEABLE
R21	0.018	REPLACEABLE
R22a	0.016 (DIA.)	BOLT ON RESISTOR BLOCK WITH REPLACEABLE RESISTORS
R22c	0.032 (DIA.)	
R23a	0.016 (DIA.)	BOLT ON RESISTOR BLOCK WITH REPLACEABLE RESISTORS
R23c	0.[illegible] (DIA.)	
R27	0.012 (DIA.)	REPLACEABLE
R28	0.012 (DIA.)	REPLACEABLE
R29	0.015 x 0.015 x 0.020 LONG	ELECTROFORMED ON IC
R30	0.047 x 0.050	ELECTROFORMED ON IC
R31	0.027 x 0.027	ELECTROFORMED ON IC

Figure 1. Lot One System Schematic.

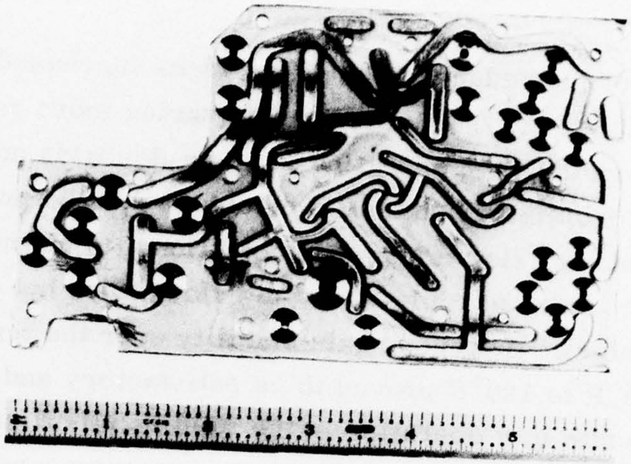
ELECTROFORMED STANDOFFS

The number of "O" rings used in the interface between the IC and the housing was cut in half by the use of electroformed standoffs in place of the replaceable mechanical standoffs. In the past, the mechanical standoffs would sometimes cock, preventing a good seal and, therefore, would require reassembly. Assembly of these two units was also greatly simplified as the need for aligning 23 standoffs was eliminated.

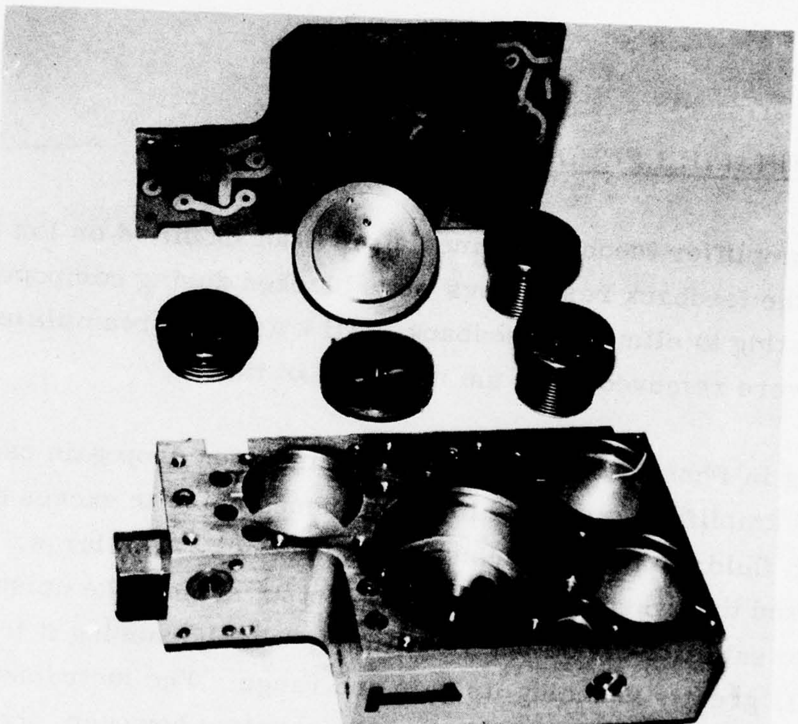
Configuration of the IC baseplate was also simplified, as it was no longer necessary to mill channels in the baseplate to route signals below the mechanical standoffs; the channels could be run directly to the electroformed standoffs with the wax mandrel. Figure 2 is a comparison between the Phase I and Phase II standoffs. Throughout Phase II, the electroformed standoffs proved to have all of the advantages anticipated without any detectable performance degradation.

PREAMPLIFIER STAGES

Noise was reduced by restricting the flow to critical preamplifier stages in which reduced range would not be a problem. As a restriction in the power supply could introduce noise, the restriction was placed in the return line of the amplifiers. As shown in Figure 1, all stages except the output stage were restricted with the equivalent of a 0.027-inch by 0.027-inch restrictor in their return line. Amplifiers A_0, A_1 and A_2 used a single 0.047-inch by 0.050-inch restrictor in a common channel to simplifiy the design. The return schematic of Figure 1 indicates the location of these restrictors. Reducing flow to the preamplifier stages was significant in reducing system noise, and these modifications were retained in all subsequent lots.



a. Phase I Integrated Circuit.



b. Phase II Integrated Circuit with Controller.

Figure 2. Phase I and Phase II Integrated Circuits.

A disadvantage of the reduced supply flow is its increased sensitivity to changes in fluid viscosity. Amplifier gain varies more rapidly with a variation in viscosity when operating in a low Reynolds number range. The best of both configurations could be obtained if the preamplifiers were operated at high flow under cold conditions (to maintain higher gain when noise is not a problem) and low flow under hot conditions (to maintain low noise). However, gain stability over the temperature range from 100°F to 180°F proved to be satisfactory and comparable to or better than units now operating in the field in TH-57 and OH-58 helicopters. Improving operation at lower fluid temperatures would require significant circuit changes and/or a means of scheduling flow as a function of fluid viscosity. This task was felt to be beyond the scope of Phase II.

PREAMPLIFIER FEEDBACK

IC preamplifier feedback channels were not modified on Lot one; however, the feedback restrictors were blocked during component and system testing to eliminate feedback. All traces of preamplifier feedback paths were removed from the mold in Lot three.

Testing in Phase I indicated that this high open-loop gain cascade (operational amplifier) produced high-frequency noise in excess of 100 Hz. At high fluid temperature conditions, this noise was large. It was theorized that when amplified by the output stages, the noise was sufficient to saturate the output amplifier (probably causing it to go turbulent), greatly reducing its gain and range. The instrumentation used was unable to detect the high-frequency noise; however, the reduction in gain and range was readily apparent as oil temperature was increased.

One disadvantage of eliminating preamplifier feedback is an increase in gain change as a function of temperature. Although the use of feedback reduces gain change and null offset, it often requires more amplifier stages to obtain the desired gain, thereby compounding the temperature problem on one hand while reducing it on the other.

Elimination of feedback also required a reduction of cascade open-loop gain. Lot one used a lower-gain, high-input-impedance amplifier to reduce the preamplifier cascade gain. Interstage bleeding and other attenuation methods were also used to reduce preamplifier gain in Lot one, but the gain remained excessive until the Lot two modifications.

FOUR-PORT RATE SENSOR PICKOFF

The configurations of the rate sensor pickoff and the controller housing were modified to accept a four-port sensor configuration. Two parallel sets of pickoffs tend to have offsets in the opposite direction, causing many error sources to cancel when the outputs are summed. Doubling the number of pickoff ports also reduces the sensor output impedance by about 50 percent, while increasing loadability (flow-loaded gain).

Four-port pickoffs were used on all three lots of Phase II; however, the short-stem pickoff was used in Lot one, and a long-stem pickoff was used in the remaining two lots. Relative advantages of short- and long-stemmed pickoffs will be discussed in the next section.

PID LINK

Pinning the PID link to the shaft, which is a positive locking technique, eliminated a slippage problem that occurred in the Phase I qualification tests. The modification was used on all Phase II units, and no similar problems were experienced.

LINEAR HIGH-PASS BELLOWS

Electroformed high-pass bellows were purchased from an outside vendor in accordance with Honeywell requirements for effective area, spring rate linearity, and range. These bellows were satisfactory on all three lots of Phase II and will be used in Phase III production. Problems associated with nonlinear bellows were eliminated.

SYSTEM RETURN

Phase I testing indicated that installation of the system return on the bottom cover reduced noise. The new location was used successfully on all three lots of Phase II and will be used on the production phase. Testing to demonstrate the degree of improvement realized by the new location was not repeated in this phase.

"O" RING GROOVES ON EXTERNAL RESISTORS

Problems of signal blockage and the generation of contamination were associated with the -004 "O" rings in Phase I. Modification of the resistor baseplate to incorporate larger -005 "O" rings proved to be a satisfactory solution and will be used in the production phase.

LOT ONE SYSTEM PERFORMANCE SUMMARY

Lot One testing was an evaluation of the production test station, the test procedure, and the Lot one hardware. In general, all three later required modifications for Lot two.

Figure 3 shows the performance of Lot one pilot input devices (PIDS). All three curves show a large hysteresis (which was determined to be part of the test setup), a substantial amount of nonlinearity at the ends (which was partially due to a poor impedance match with the simulated load), and a relatively large difference in gain between the three units. PID performance, summarized in Table 1, indicates that the variation in gain is relatively large considering that the components were selected to be identical.

TABLE 1. PID DATA SUMMARY

PID S/N	Gain (psid/in.)	Sleeve S/N	Slot Width (in.)	Slot Length (in.)	Bore Diameter (in.)	Spool Diameter (in.)
1	1.53	10	0.0040	0.4500	0.25010	0.24940
2	1.14	21	0.0040	0.4484	0.25015	0.24925
3*	1.50	24	0.0040	0.4476	0.25015	0.24940

*Used in first system.

Lot one rate sensor performance was excellent, as shown in Figure 4. Linearity is required to be within ±10 percent. Actual performance was better than this by one or two orders of magnitude, eliminating the need to measure this parameter. Gain is constant within a few percent, and loading has a minimal effect on sensor gain. Offset was only about 20 degrees per second and was consistent from unit to unit. System tests on Lot one showed that the sensor scale factor decreased by about

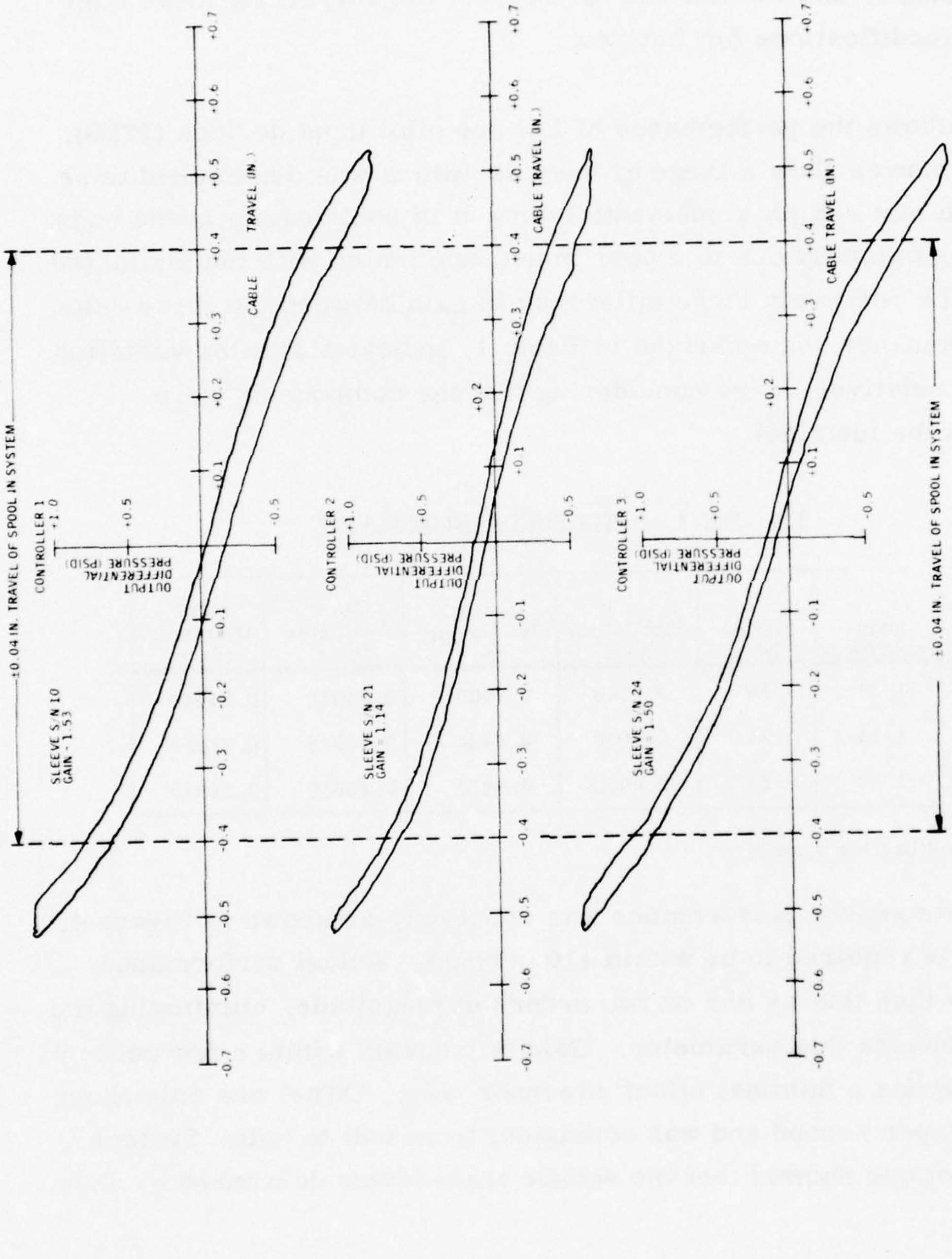


Figure 3. Summary of Lot One Test Results.

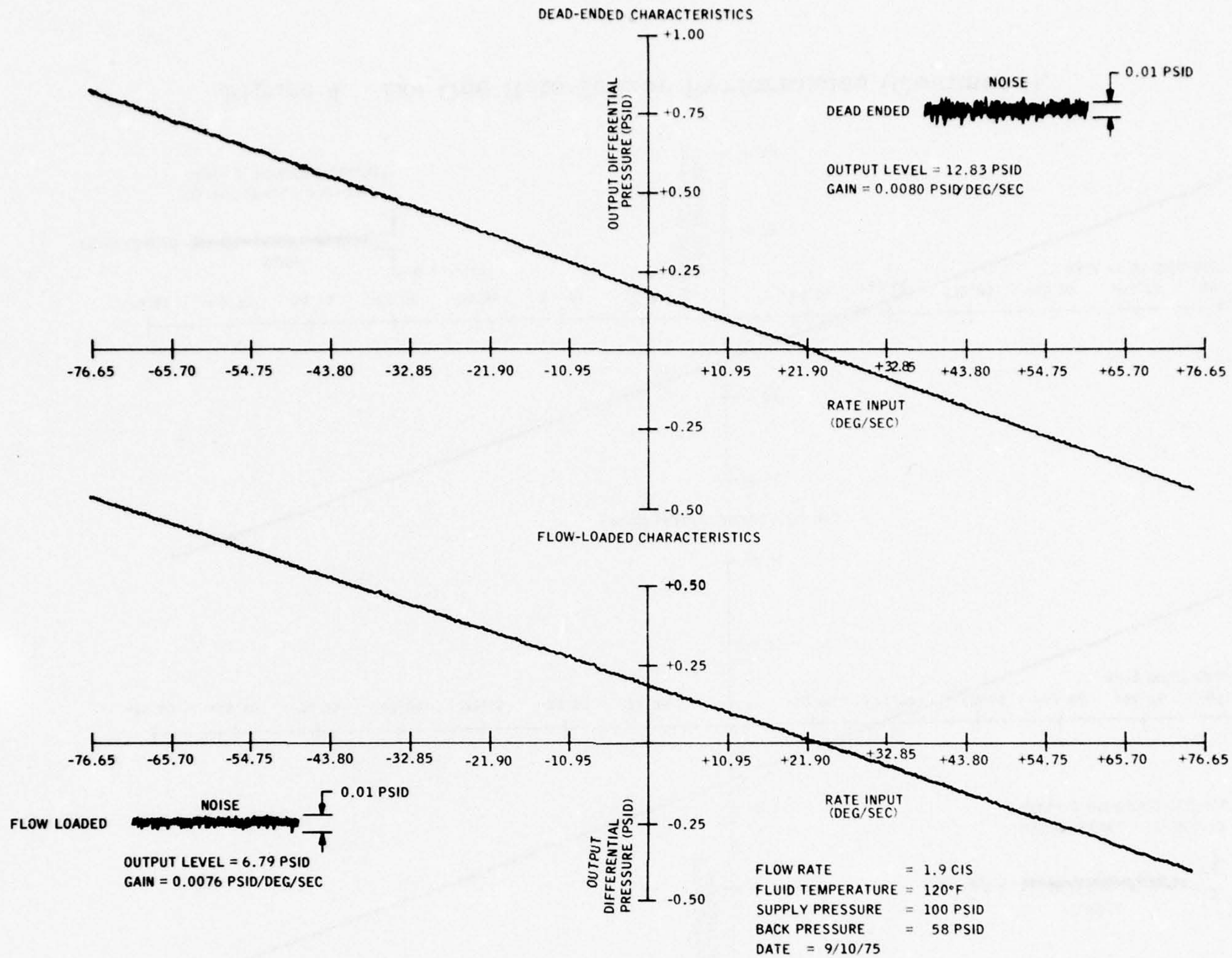


Figure 4. Lot One Rate Sensor Performance.

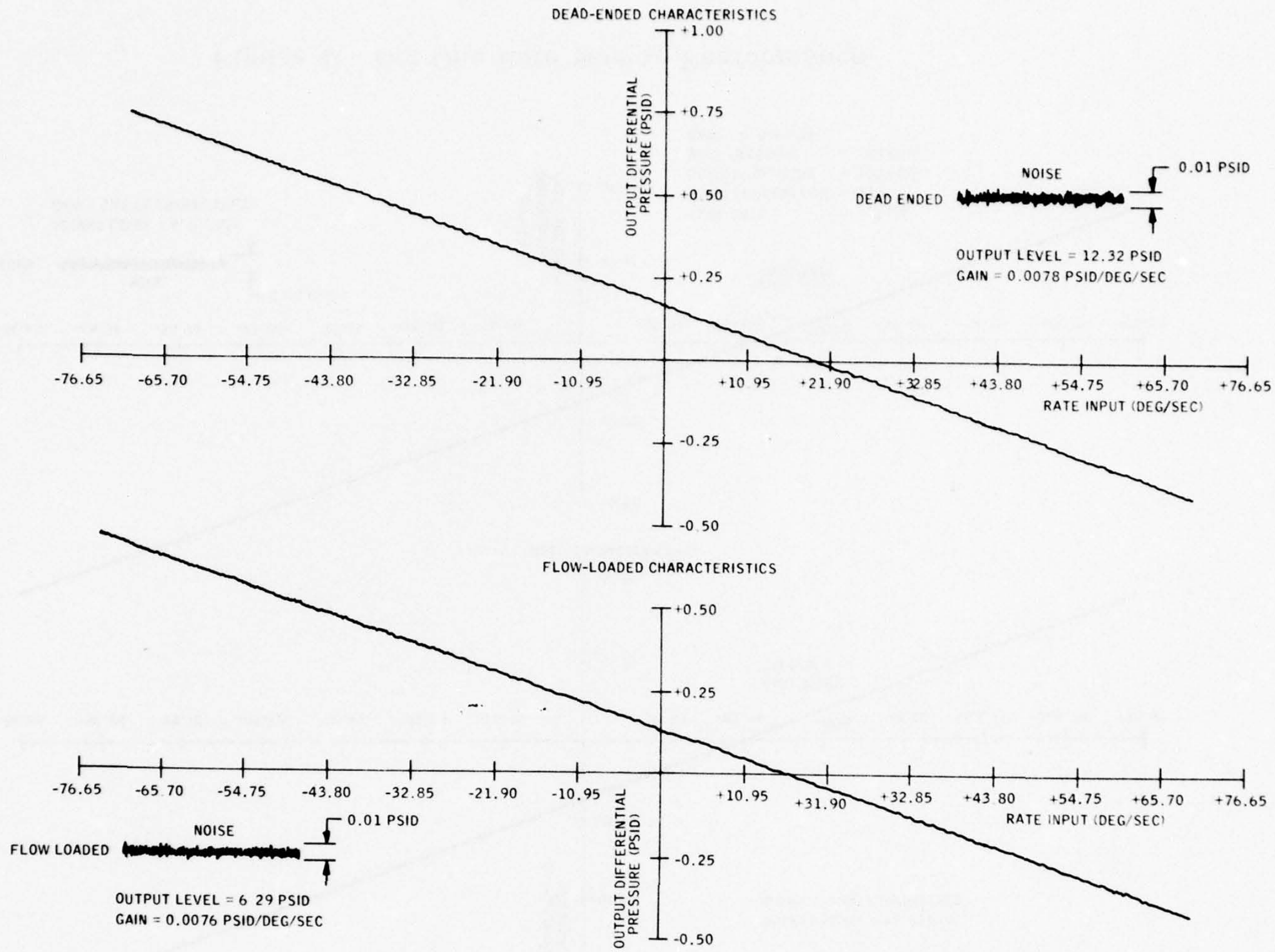


Figure 4. Lot One Rate Sensor Performance (Continued).

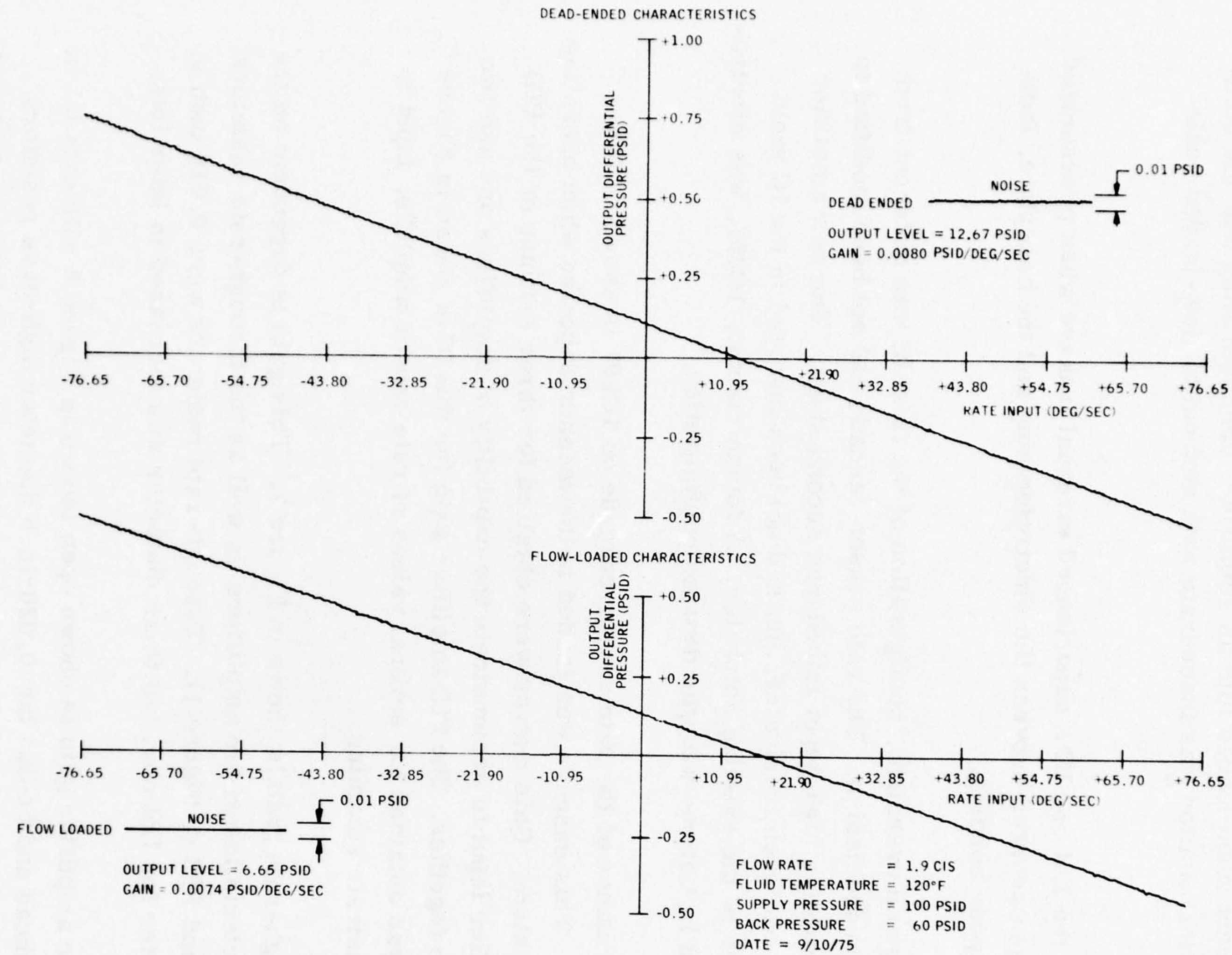


Figure 4. Lot One Rate Sensor Performance (Concluded).

60 percent when loaded into an amplifier, demonstrating that the component test station was inaccurate with respect to flow-loaded scale factor.

One of the Lot one IC's experienced external leakage when pressurized. Leakage occurred between the electroforming and the baseplate, indicating poor bonding.

Through an oversight, configuration of the first IC was different from the intended design. The rate sensor cascade had not been modified to incorporate a high-input impedance second stage. The new amplifier (mold) had been fabricated, but had not been inserted in the IC mold in place of the existing amplifier. A fourth circuit, 1C807, was electroformed in Lot one with the desired configuration.

Performance of the rate sensor cascade on 1C807 is shown in Figure 5. This cascade was loaded in the manner expected when operating in a system. Gain curves were obtained for three settings of the PID amplifier input to demonstrate the capability of amplifiers one and two to sum together. The PID amplifier gain for this IC is shown in Figure 6. Data was obtained for several values of rate sensor amplifier input to demonstrate summing.

Through-rate gain is shown in Figure 7. This gain is dependent on the characteristics of the amplifiers as well as the through-rate resistors (R22 and R23 of Figure 1). Through-rate resistors were 0.016 inch in diameter for Lot one, but their diameter was increased in later lots.

Driver amplifier gain is shown open looped in Figure 8 with data taken both ahead and behind the 0.020-inch diameter high-pass resistors (R8 and R9 of Figure 1). Data for the remaining two IC's are included in Section V, Component and System Performance Summary.

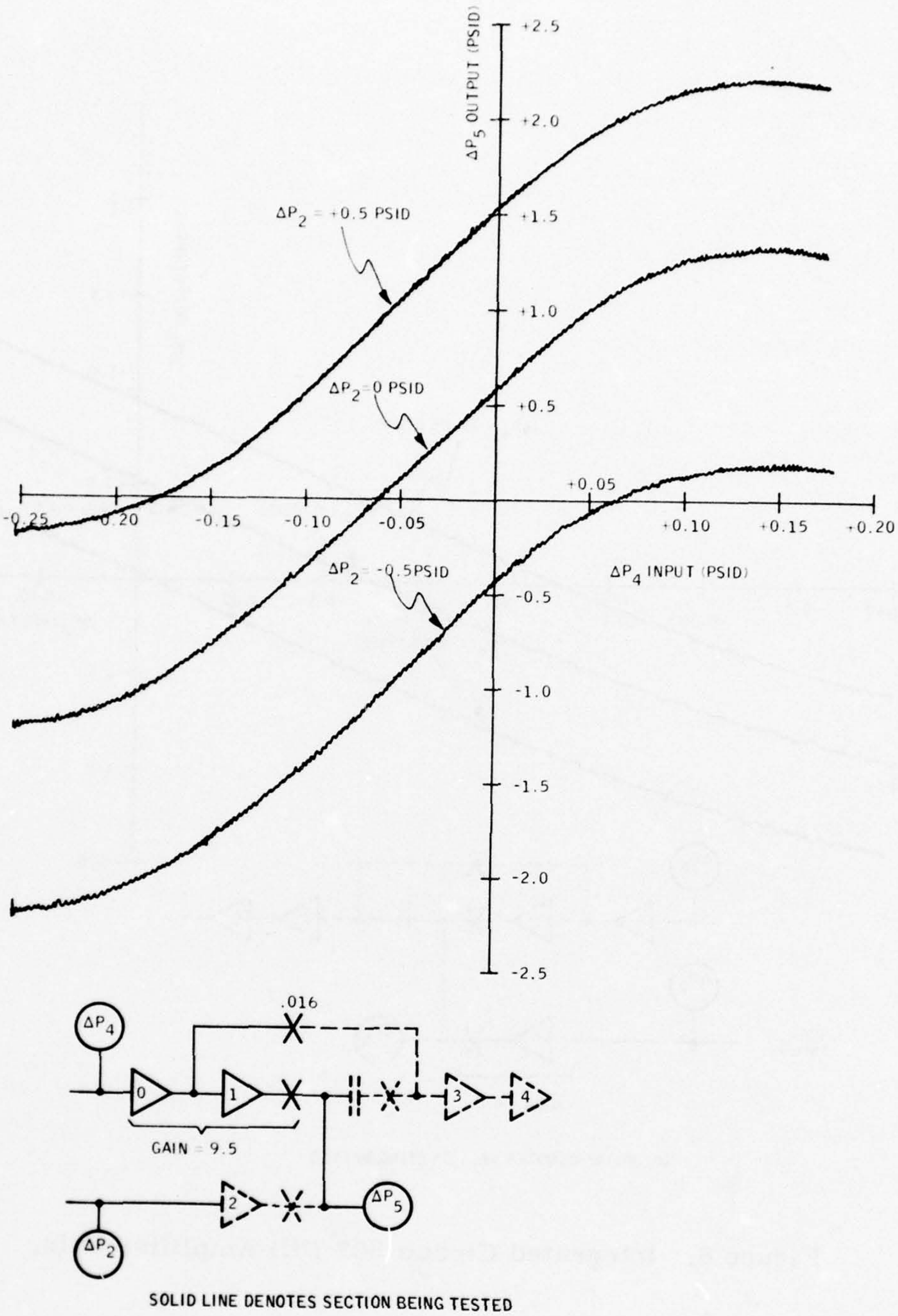
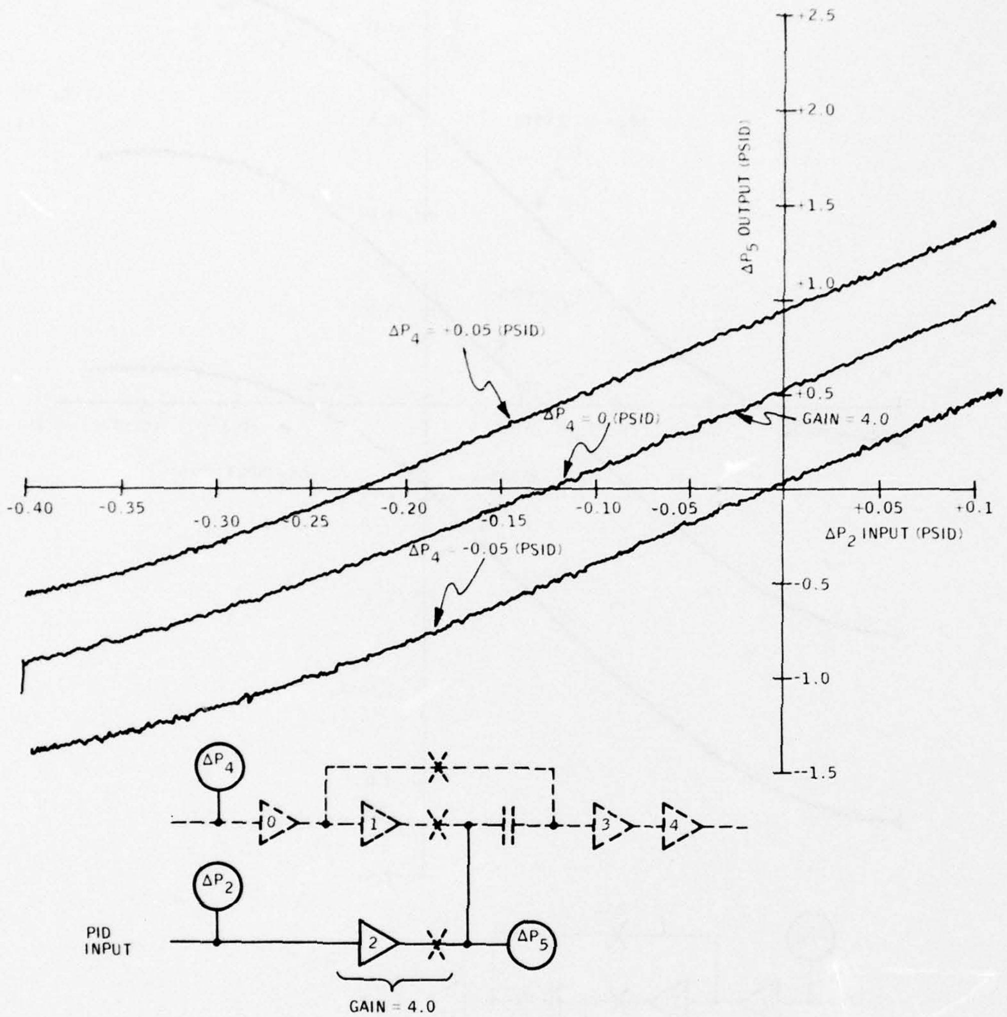


Figure 5. Integrated Circuit 807 Rate Sensor Cascade.



SOLID LINE DENOTES SECTION BEING TESTED

Figure 6. Integrated Circuit 807 PID Amplifier Gain.

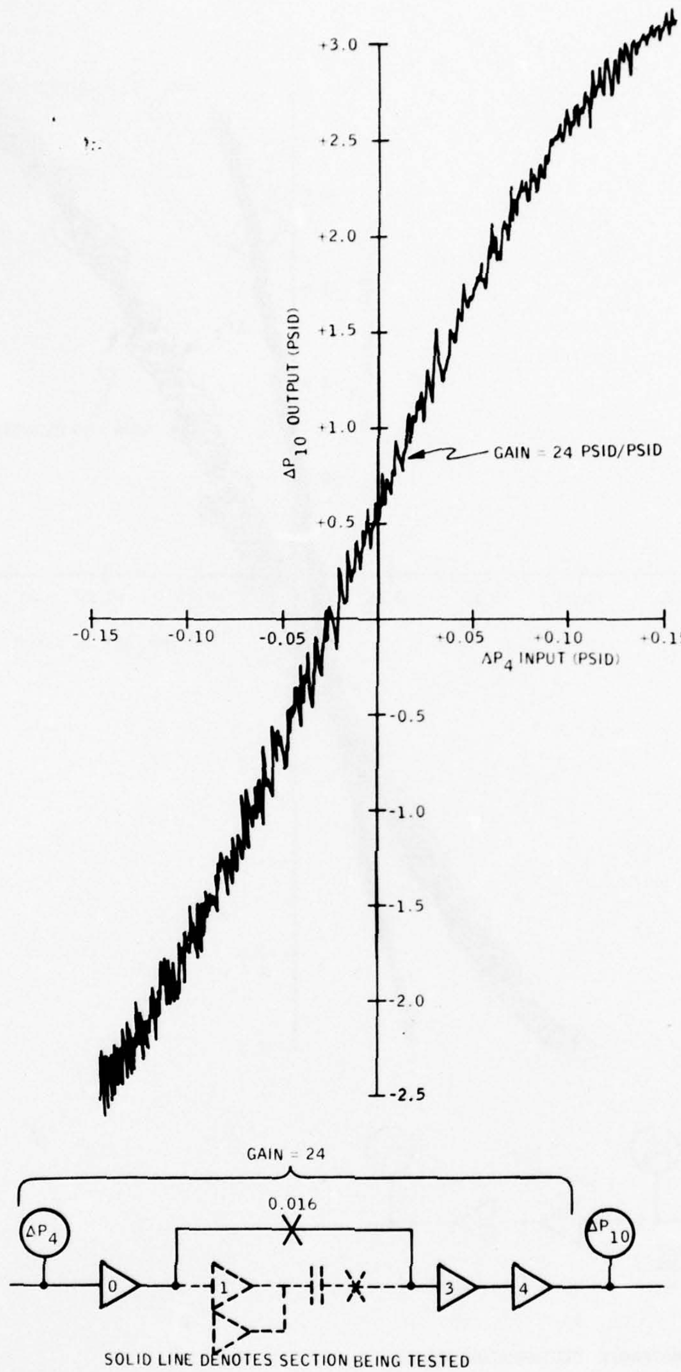


Figure 7. Integrated Circuit 807 Through-Rate Gain.

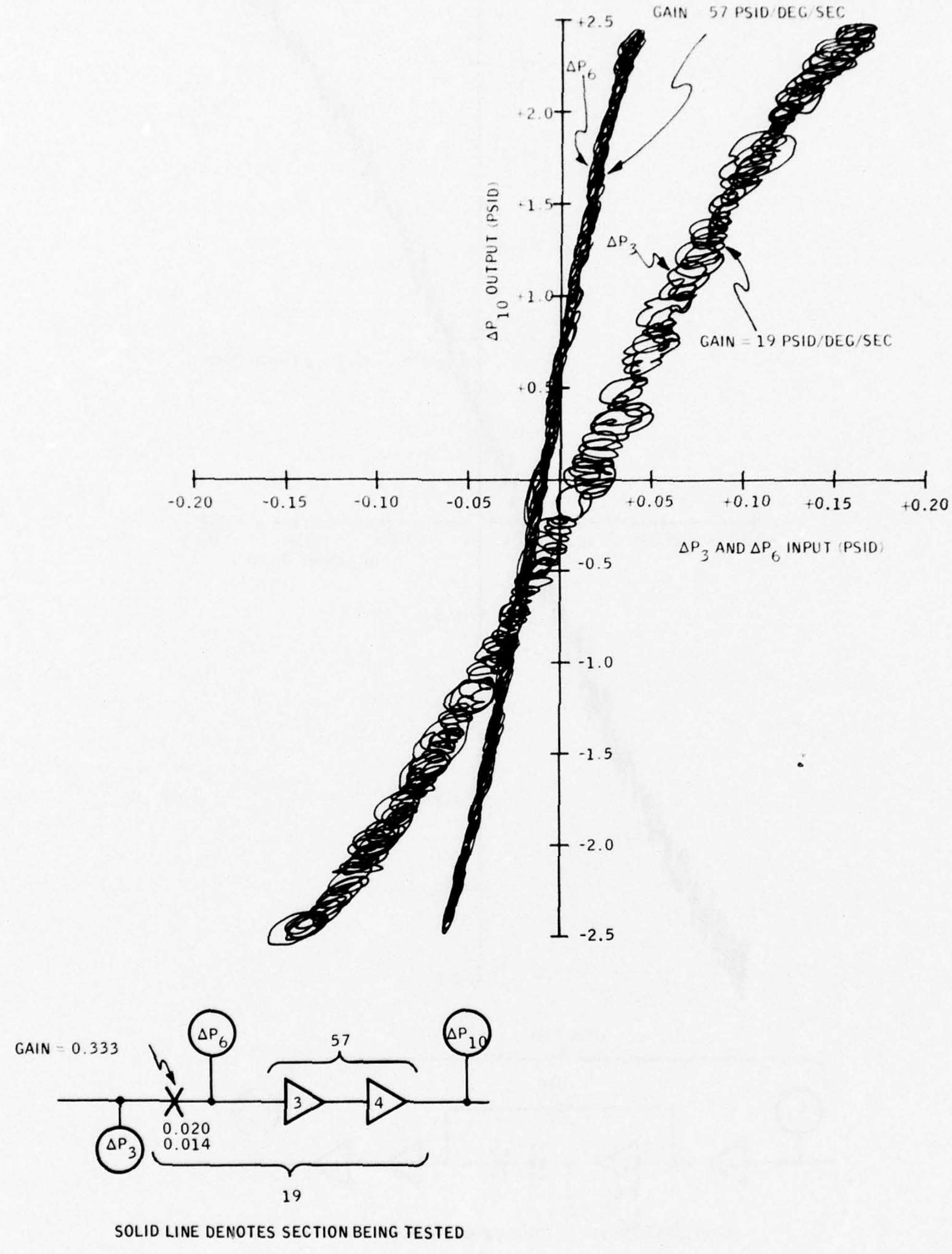


Figure 8. Integrated Circuit 807 Driver Amplifier Gain.

A system was assembled using rate sensor Number 2, PID Number 3 and IC Number 807. Size and location of the various restrictors are shown in Figure 1. Table 2 gives the system performance requirements versus test results.

TABLE 2. SYSTEM PERFORMANCE REQUIREMENTS VERSUS TEST RESULTS

Parameter	120°F Requirement	Test Results
High-Pass Rate Gain	0.153 ±0.019 psid/deg/sec	0.169 psid/deg/sec
Through-Rate Gain	0.033 ±0.005 psid/deg/sec	0.03 psid/deg/sec
PID Gain	33.4 ±4.2 psid/in.	17.0 psid/in.
Noise (120°F)	±0.2 psid	±0.02 psid
Noise (178°F)		±0.25 psid
Offset	±0.4 psid	-0.3 psid

Note that the PID gain is low while all other characteristics are within the specification limits. Numerous techniques were used to reduce the rate cascade gain, and thereby, permit a higher output cascade gain (use) less feedback in R10 and R11). Reducing the rate cascade to half and doubling the output cascade gain would result in a rate gain of 0.169 psi/deg/sec and a PID gain of 34 psid/in. Frequency response, which was normalized to the nominal PID gain, is shown in Figures 9 and 10. Response is within the established limits. Gain change as a function of temperature is shown in Figure 11. System noise was excessive at and above 160°F when the larger 0.032-inch power supply restrictor was used. With the 0.030-inch restrictor, rate gain was maintained within a ±2 dB limit from 104°F to 180°F.

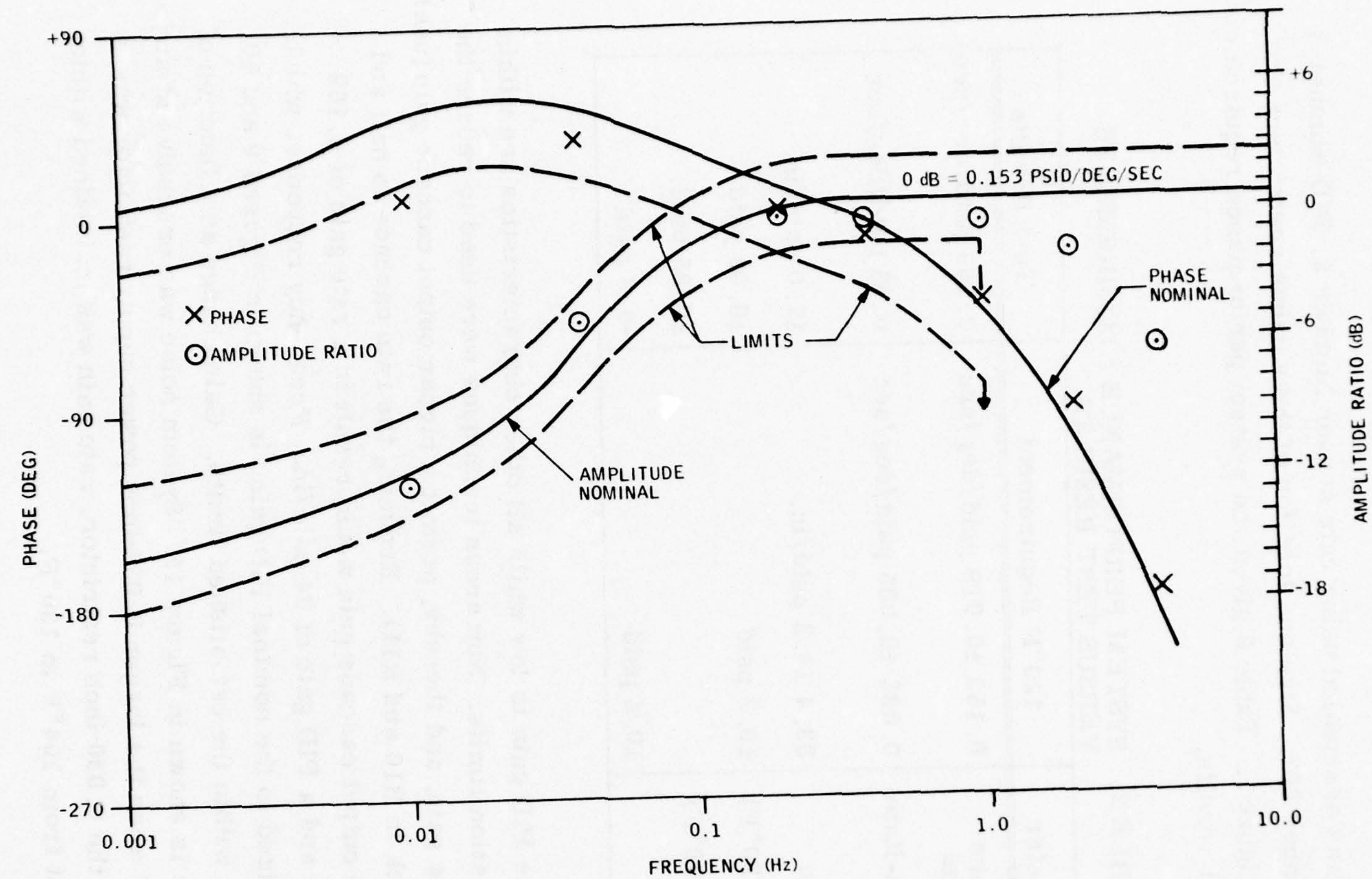


Figure 9. Lot One System Rate Loop Frequency Response.

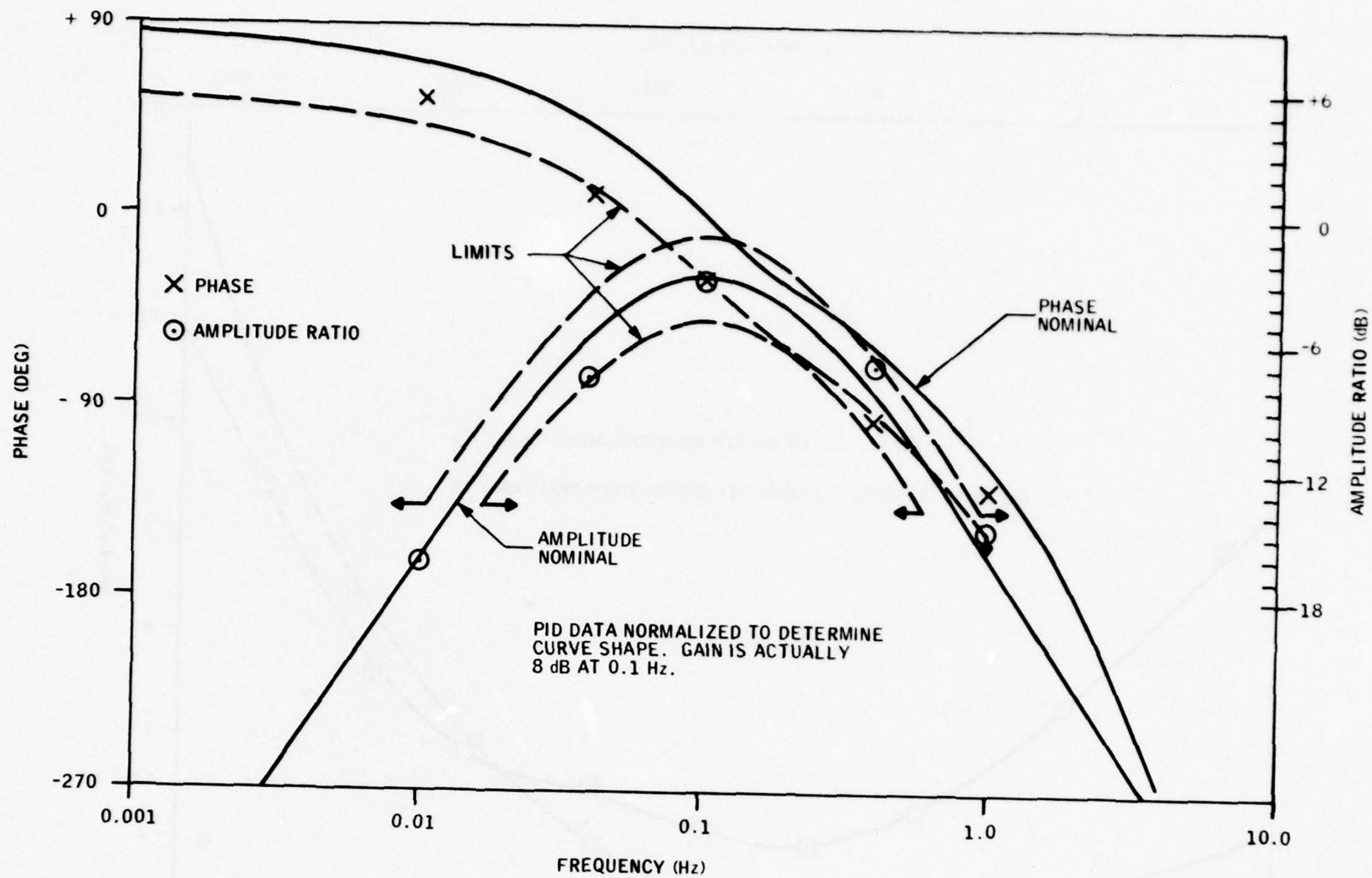


Figure 10. Lot One PID Loop Frequency Response.

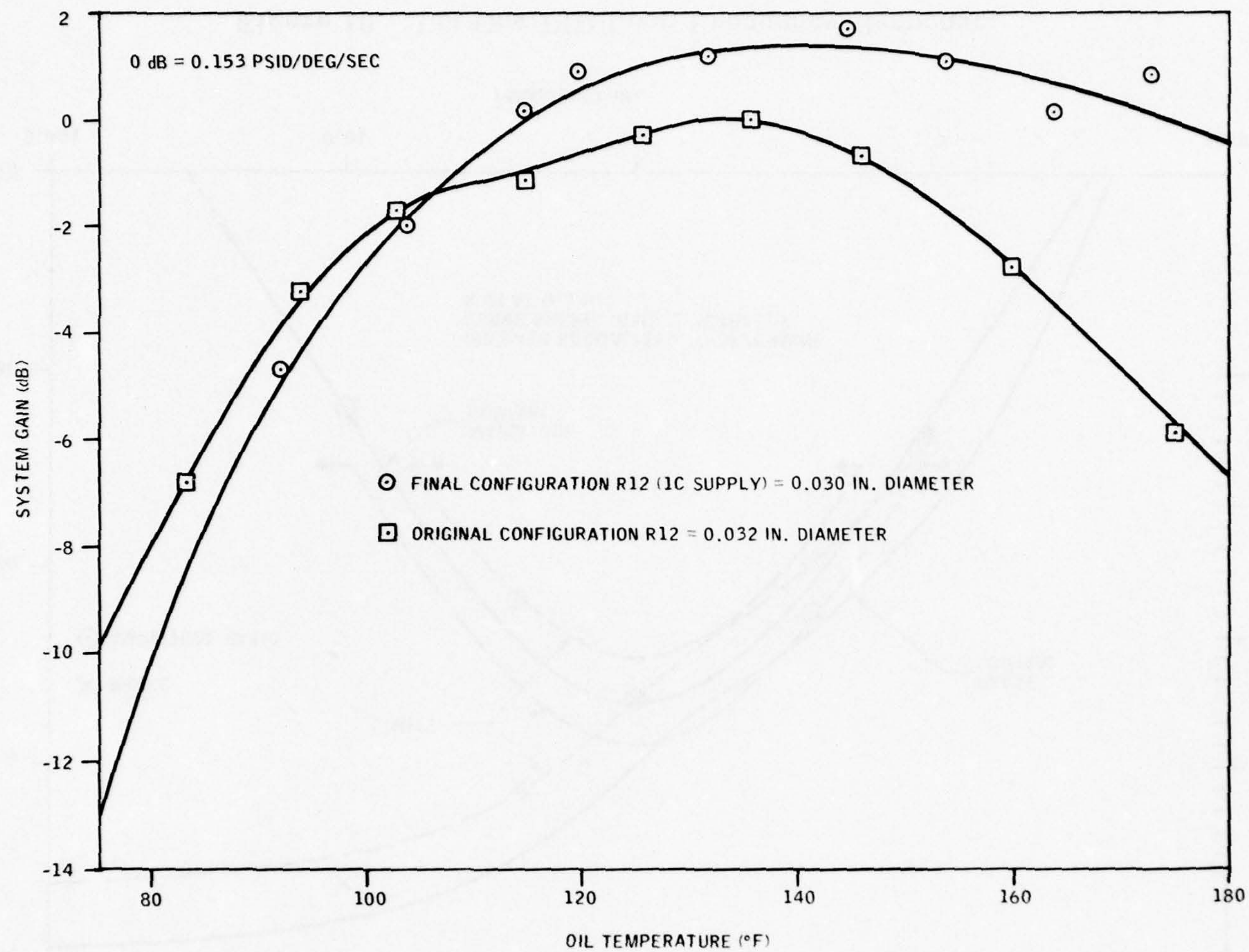


Figure 11. Lot One System Rate Gain as a Function of Temperature.

Pressure taps were provided on the housing of the Lot one system to measure signals at the output of the rate sensor and at the input to the high-pass bellows. Tests on the rate sensor showed a dead-ended gain of 0.0078 psid/deg/sec (Figure 12), which is identical to that obtained on the component tests (see Figure 4, rate sensor Number 2); however, the flow-loaded gain was only 0.003 psid/deg/sec in the system as compared to 0.0076 psid/deg/sec in the component test fixture. The need for a change in component test fixture loading was indicated.

Lot one system test results indicated that satisfactory gains could be obtained if one of the preamplifier stages was eliminated from the circuit. Eliminating one preamplifier stage would require the rate sensor output to be split between the preamplifier and the through-rate restrictors. Additional tests were conducted to evaluate the effect of this higher rate sensor loading.

Gain data were obtained with three types of load on the rate sensor as shown in Figure 13. Load A is the configuration used in the Lot one system where the rate sensor drives only one component, the rate cascade. Load B is the same as load A except that the IC operating level (therefore, the input amplifier control port level) is biased up by adding a 0.072-inch-diameter restrictor under its return standoff. Load C represents the loading that would be experienced if only one rate sensor cascade amplifier was used. With load C, the rate sensor drives an amplifier in parallel with a set of 0.016-inch-diameter bleed resistors to ground.

Test results are summarized in Table 3. Three rate sensors were used to show that the specific conclusions obtained would apply to all production units. Serial Numbers (SN) 2 and 3 have a short output stem, and their ports have a lower output pressure level than SN 706 sensor, which has a long stem. Matching between the sensor and

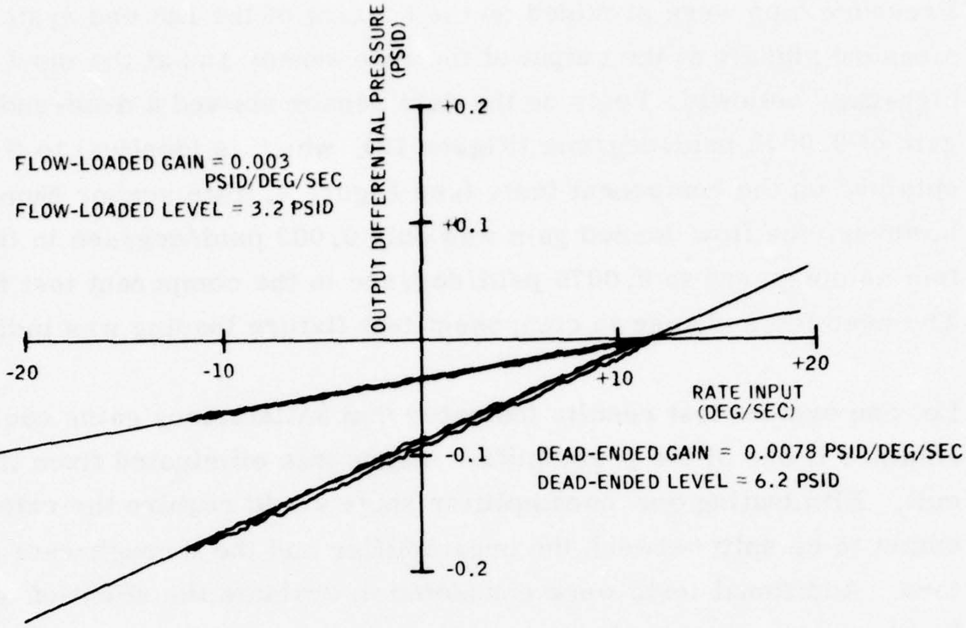


Figure 12. Lot One Rate Sensor Performance.

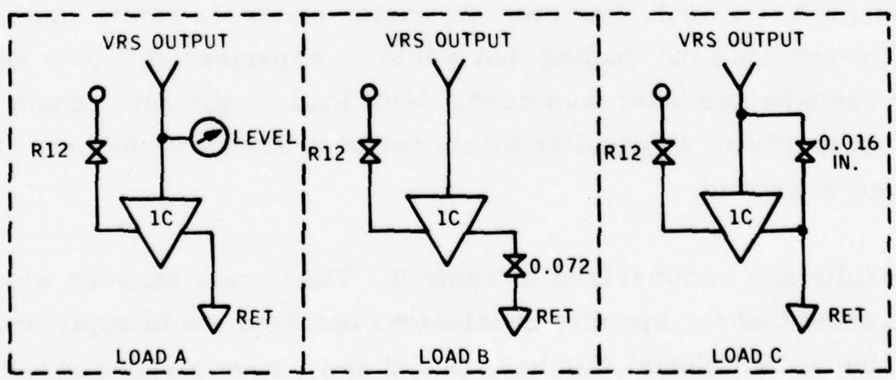


Figure 13. Simplified Circuit.

TABLE 3. SUMMARY OF LOT 1 TEST RESULTS

VRS S/N	R12 Diameter (in.)	Load	Gain (psid/deg/sec)	Level (psi)	Oil Temperature (°F)
2	0.030	A-807	0.0029		170
2	0.030	A-807	0.0026	3.2	107
2	0.032	A-807	0.00225		103
2	0.032	B-807	0.0019		120
2	0.030	A-807	0.00275		120
2	0.030	A-805	0.00287		120
3	0.030	A-805	0.0033		108
3	0.030	C-805	0.00225		110
706	0.030	A-805	0.0042	6.2	96
706	0.030	A-807	0.004		100
706	0.030	A-807	0.0045		120
706	0.030	C-807	0.0028		120

amplifier was significantly better with the long-stem pickoff, SN 706. Indications are that when levels between the pickoff and the amplifier control ports approach each other, the reduction in flow from the pickoff to the amplifier results in a reduced amplifier input impedance. This same characteristic was noted when the control port level was raised by the use of an IC back-pressure resistor, load B. Input characteristics of IC's 805 and 807 should be identical, and performance was essentially the same with both units. Additional loading on the rate sensor with load C significantly reduced its gain; however, this reduction was less with the long-stemmed pickoff.

SECTION III
LOT TWO

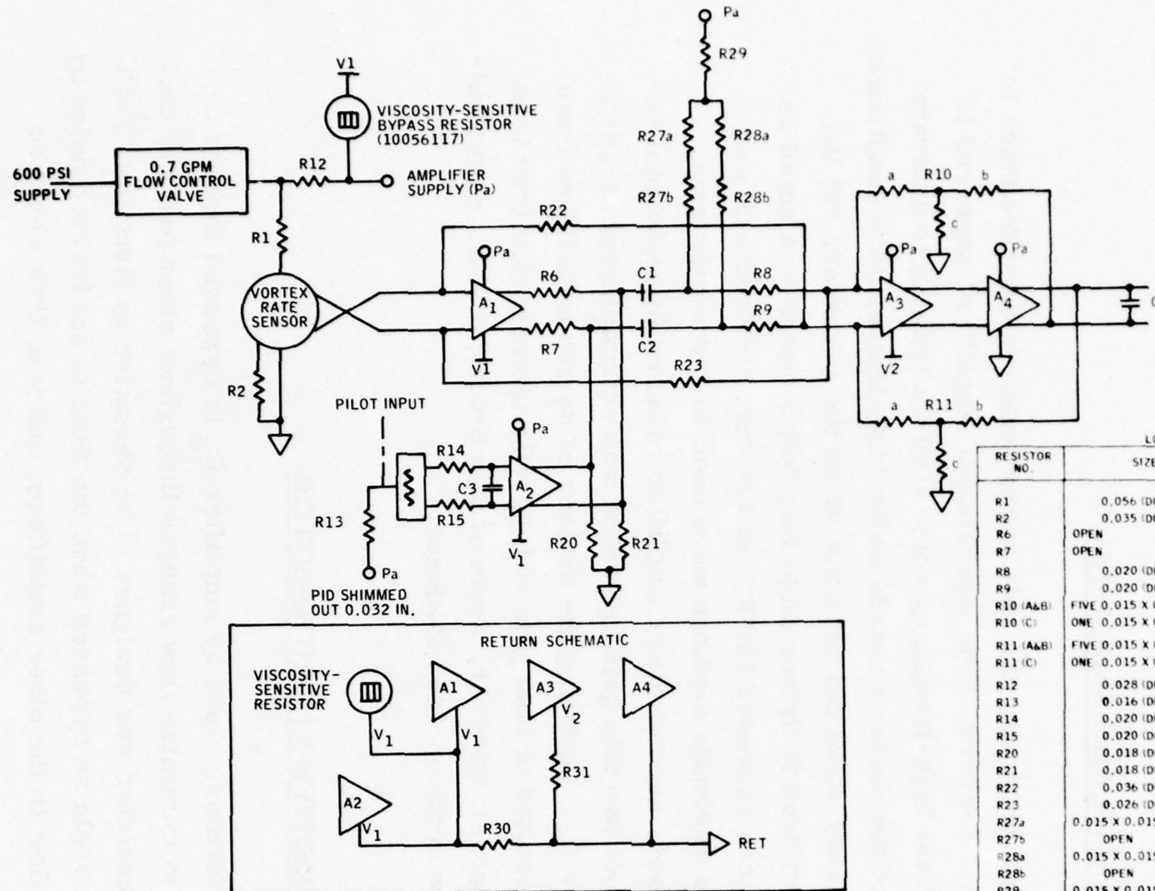
SYSTEM CONFIGURATION SUMMARY

Hardware changes for Lot two were:

- Elimination of one stage of amplification in the rate sensor cascade
- Use of a viscosity-sensitive bleed resistor in place of the eliminated amplifier
- Fabrication of a long-stem, four-port rate sensor pickoff
- Increase in the width of the PID amplifier control ports from 0.010 inch to 0.015 inch
- Electroforming of the bias restrictors, $R27_a$ and $R28_a$ (see Figure 14 for location), into the integrated circuit

Test fixture changes for Lot two were:

- Increase in PID loads from 0.018 inch to 0.022 inch
- Recording of PID spool travel rather than PID arm travel on test data
- Increase in rate sensor load resistors from 0.014 inch to 0.025 inch in diameter to provide representative loading on the sensor pickoff



LOT TWO RESISTORS

RESISTOR NO.	SIZE (IN.)	CONFIGURATION
R1	0.056 (DIA.)	DRILLED IN HOUSING
R2	0.035 (DIA.)	REPLACEABLE
R6	OPEN	REPLACEABLE
R7	OPEN	REPLACEABLE
R8	0.020 (DIA.)	REPLACEABLE
R9	0.020 (DIA.)	REPLACEABLE
R10 (A&B)	FIVE 0.015 X 0.015 IN SERIES	THREE BRANCH NETWORK ELECTROFORMED ON A BOLT ON ASSEMBLY
R10 (C)	ONE 0.015 X 0.015	
R11 (A&B)	FIVE 0.015 X 0.015 IN SERIES	THREE BRANCH NETWORK ELECTROFORMED ON A BOLT ON ASSEMBLY
R11 (C)	ONE 0.015 X 0.015	
R12	0.028 (DIA.)	REPLACEABLE
R13	0.016 (DIA.)	REPLACEABLE
R14	0.020 (DIA.)	REPLACEABLE
R15	0.020 (DIA.)	REPLACEABLE
R20	0.018 (DIA.)	REPLACEABLE
R21	0.018 (DIA.)	REPLACEABLE
R22	0.036 (DIA.)	REPLACEABLE
R23	0.026 (DIA.)	REPLACEABLE
R27a	0.015 X 0.015 X 0.070 LONG	ELECTROFORMED ON IC
R27b	OPEN	REPLACEABLE
R28a	0.015 X 0.015 X 0.070 LONG	ELECTROFORMED ON IC
R28b	OPEN	REPLACEABLE
R29	0.015 X 0.015 X 0.020 LONG	ELECTROFORMED ON IC
R30	0.047 X 0.050	ELECTROFORMED ON IC
R31	0.027 X 0.027	ELECTROFORMED ON IC

Figure 14. Lot Two System Schematic.

Major investigations during fabrication of Lot two were directed to:

- Resolving electroforming problems (bonding)
- Performing a PID parameter variation study

RATE SENSOR CASCADE AMPLIFIER

In Phase I of this program, the rate sensor cascade used feedback to reduce its gain. However, this "operational amplifier" appeared to generate sufficient high-frequency noise (100 Hz typical) to saturate the last stage of the driver cascade under high-temperature conditions. The high-frequency noise did not show up on the recorder, but the resultant sudden drop in driver amplifier output range was noted as fluid temperatures exceeded 150°F. In Lot one, the feedback was eliminated, and alternate methods were used to reduce the gain. A high-impedance, second-stage amplifier resulted in some gain reduction. For Lot two this gain reduction was accomplished by eliminating amplifier A_o. Reducing the number of series amplifiers from four to three resulted in less gain change with temperature (one less amplifier to change); however, some of this benefit is lost, as the output cascade now requires less feedback.

VISCOSITY-SENSITIVE BLEED RESISTOR

Flow that was formerly used by amplifier A_o is bypassed through a bleed resistor to minimize flow changes throughout other parts of the circuit. This resistor was designed to be sensitive to viscosity, such that more flow would be bypassed when the fluid is hot (reduce noise by supplying less flow to the other amplifiers) and less flow would be bypassed when the fluid is cold (to improve low temperature gain by supplying more flow to the other amplifiers).

The configuration of this restrictor is shown in Figure 15. Five bypass channels are 0.014 inch wide by 0.018 inch deep by 0.265 inch long. The area of this bypass is:

$$\begin{aligned} &\text{Area bypass} = 5 \times 0.014 \times 0.018 = 0.00126 \text{ in.}^2 \\ &\text{Area of a power nozzle} = 0.025^2 = 0.000625 \text{ in.}^2 \\ &\text{Area bypass/area power nozzle} = 2.016 \end{aligned} \tag{1}$$

Under very high temperature conditions, this restrictor could bypass nearly twice the flow of an amplifier. Viscosity-sensitive resistance of a channel is

$$R_\nu = \frac{1.325 \times 10^{-6} \nu L}{C^3 W \left(\frac{W}{C + W}\right)^2} \tag{2}$$

where

R_ν = viscosity-sensitive resistance, lb-sec/in.^{5}

C = channel height (in.)

W = channel width (in.)

L = channel length (in.)

ν = fluid viscosity centistokes

For a power nozzle that is 0.025 inch by 0.025 inch by 0.20 inch,

$$R_\nu = \frac{1.325 \times 10^{-6} \times 0.20 \nu}{0.025^3 \times 0.025 \left(\frac{0.025}{0.025 + 0.025}\right)^2} = 2.7 \nu \Omega \tag{3}$$

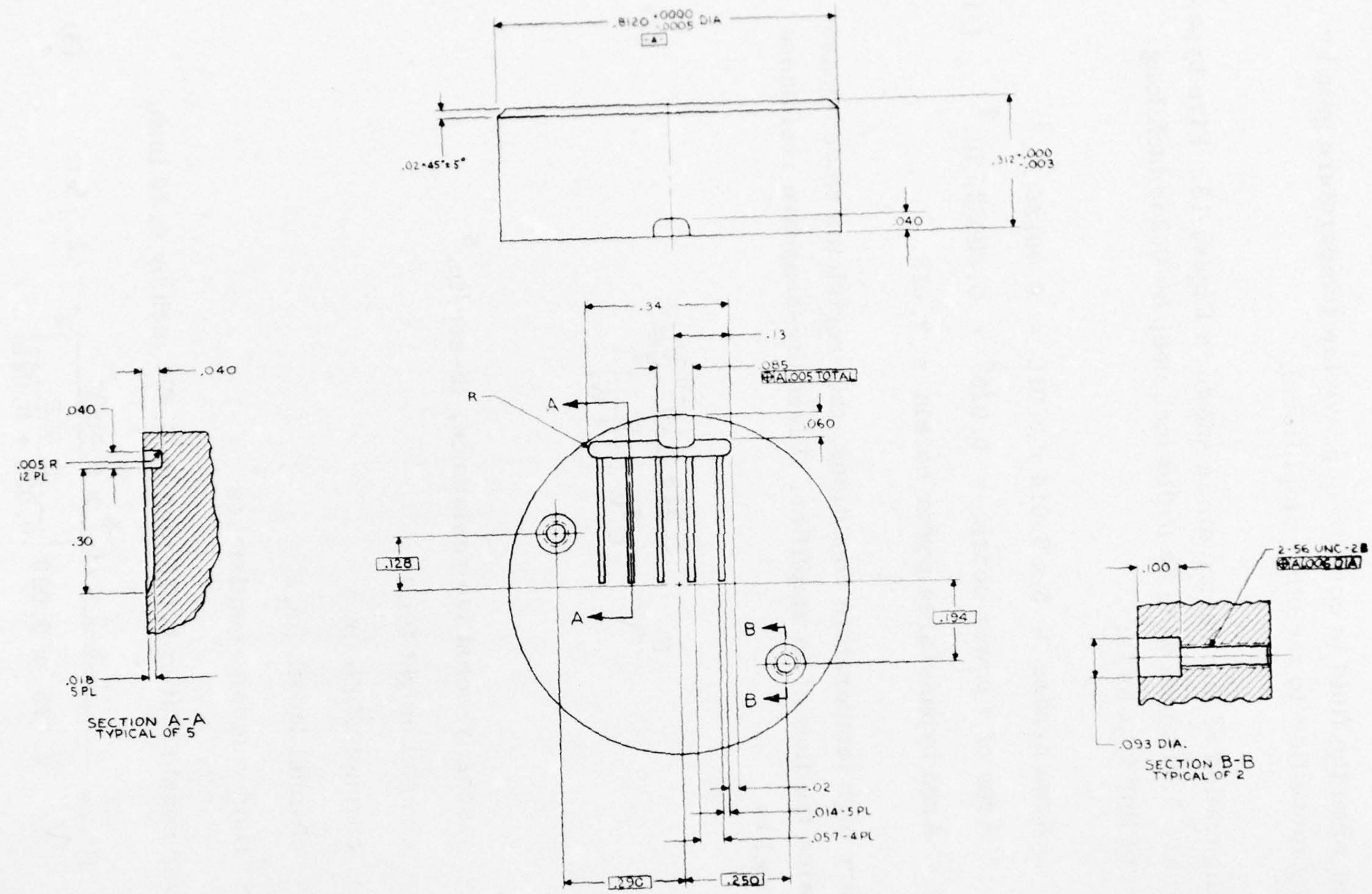


Figure 15. Bleed Resistor Schematic.

For a channel that is 0.014 inch x 0.018 inch x 0.265 inch long,

$$R_{\nu} = \frac{1.325 \times 10^{-6} \times 0.265\nu}{(0.018)^3 \times 0.014 \left(\frac{0.014}{0.018 + 0.014}\right)^2} = 22.47\nu\Omega \qquad (4)$$

Five such channels in parallel have a resistance of

$$R_{N_{\nu}} = \frac{22.47\nu}{5} = 4.5\nu\Omega \qquad (5)$$

Total differential pressure across a channel will be

$$\Delta P = QR_{\nu} + \left(\frac{Q}{103A}\right)^2 \qquad (6)$$

where

Q = flow, in.^{3}/sec

R_{ν} = viscosity-sensitive resistance lb-sec/in.^{5}

A = total channel cross-sectional area in.^{2}

For a power nozzle with a flow of 0.14 centistokes and a viscosity of 14 centistokes (about 100°F new 5606 oil) the pressure drop will be

$$\begin{aligned}\Delta P &= 0.14 \times 2.7 \times 14 + \left(\frac{0.14}{103 \times 0.025^2}\right)^2 \\ &= 5.3 \text{ psi} + 4.7 \text{ psi} = 10 \text{ psi}\end{aligned} \qquad (7)$$

For the five parallel bypass resistors, the pressure drop would be

$$\begin{aligned}\Delta P &= 0.14 \times 4.5 \times 14 + \left(\frac{0.14}{5 \times 103 \times 0.014 \times 0.018}\right)^2 \\ &= 8.8 \text{ psi} + 1.2 \text{ psi} = 10 \text{ psi}\end{aligned} \qquad (8)$$

These calculations show that flow through the selected bypass restrictor is about the same as that for an amplifier at 100°F. Bypass flow increases at higher temperature and decreases at colder temperature, providing a slight amount of temperature compensation. Because temperature compensation was not an objective of the Lot two modifications, the bypass restrictor was designed to be only slightly more sensitive to viscosity than the amplifier that it replaces. If temperature compensation was to be a major objective, the bypass resistor would be designed to have a larger cross-sectional area and a slightly larger viscosity-sensitive resistance coefficient.

FOUR-PORT LONG-STEM RATE SENSOR PICKOFF

Lot one test results presented in Table 3 showed the desirability of using a long-stem rate sensor pickoff to obtain a better match with the IC. The previously designed long-stem rate sensor pickoff configuration was used in Lots two and three.

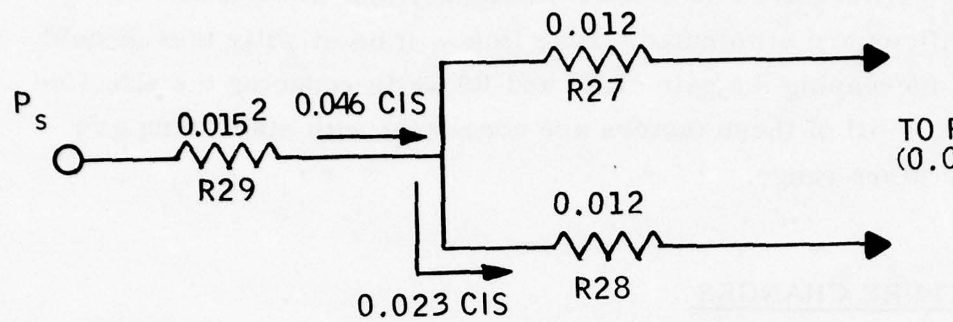
PID AMPLIFIER CONTROL PORT WIDTH

Input impedance of the PID amplifier was reduced (to better match the spool slots) by increasing the control port width from 0.010 inch to 0.015 inch. Test fixtures for evaluating the PID valves and the appropriate specifications were changed to reflect this modification.

BIAS RESISTORS

Lot one testing showed that a number of restrictors could be removed and that others could be made larger. R27 and R28 were 0.012 inch in diameter, the smallest restrictors in the system. It was decided to electroform over-size resistors in the R27 and R28 locations, which would be in series with larger replaceable resistors.

The bias circuit consists of R27, R28, and R29. For typical flow conditions:



The pressure drop across R29 is

$$\Delta P \approx \left(\frac{Q}{103A}\right)^2 = \left(\frac{0.046}{103 \times 0.015^2}\right)^2 = 3.9 \text{ psid} \tag{9}$$

where

ΔP = pressure drop, psid

Q = flow, in.^{3}/sec

A = area, in.^{2}

The pressure drop across R27 or R28 is

$$\Delta P = \left(\frac{Q}{103A}\right)^2 = \left(\frac{0.023}{103 \times \frac{\pi \times 0.012^2}{4}}\right)^2 = 3.9 \text{ psid} \tag{10}$$

Resistors R27 and R28 were replaced by an electroformed viscosity-sensitive resistor in series with a replaceable 0.014-inch diameter restrictor. With a flow of 0.023 cis, the pressure drop across the 0.015-inch by 0.015-inch by 0.0786-inch restrictors is about 2.9 psi when the fluid viscosity is 10 centistokes and the drop across the 0.014-inch-diameter orifice is 1.9 psi. The new bias circuit is somewhat more restrictive than the previous circuit if the replaceable orifices are used, and it is slightly less restrictive if the replaceable orifices are eliminated. Bias flow will be slightly less at cold temperatures, increasing the gain of R8 and R9 while reducing the effective input impedance. All of these factors are consistent with stabilizing gain over the temperature range.

PID TEST FIXTURE CHANGES

Loads on the test fixture were modified by changing the orifices from 0.018 inch to 0.022 inch in diameter to reflect the increase in the PID amplifier control port area.

Linkage on the test fixture had hysteresis, and its lever ratio was different from that on the system. Test procedures were modified to specify and record spool position rather than simulated lever position. Data are now valid for the spool and sleeve independent of the driving lever arm arrangement. Elimination of the hysteresis is another advantage of this modification.

ELECTROFORMING PROCESS

Problem

Two separate electroforming facilities were used during this program. The standard Honeywell facility was used for electroforming Lots one and two. The production facility was not debugged until completion of the Lot two investigations. Experiments on the production plating facility demonstrated marginal bonding, and investigation showed the presence of organic contaminants that may have leached out of the new plastic pumps, lines, and tanks. Removal of these contaminants, however, did not eliminate the problem of poor bond strength. Problems also began to show up on the hardware plated in the standard facility.

Two lots of rate sensors had extremely poor bonds, and one IC leaked at one location in the bond region. A detailed investigation was required to determine which parameters were marginal in the existing plating process.

There were three main steps in the electroforming process at the start of these tests. First, the parts were cleaned in a 10-percent sulphuric acid solution by connecting the positive lead of the power supply to the racked parts and by adjusting the current to a level slightly below that where bubbling occurs.

The second and most critical step was activation in a Wood's nickel strike. A 304 stainless steel component was inserted in the Wood's nickel strike tank, where it received a second cleaning with a positive current (anodic) for about one minute. The current was then reversed, and the strike was plated on the part at a current density of about 50 amperes per square foot (A/ft^2) for a period of about five minutes. Current density for this plating step was one of the critical variables under investigation. A 303 stainless steel component (303 stainless uses an additive of selenium or sulfur or a combination of both for machinability) was activated using the same 50 A/ft^2 current density for the same five-minute time period, but the anodic cleaning step in the Wood's nickel bath was eliminated. Operating the 303 anodic in the Wood's nickel bath caused the surface to turn dark. This dark surface layer formed an interface that prevented effective bonding of the electroforming.

In the final step, parts were electroformed in a Barret sulfamate nickel electroforming solution after being rinsed in deionized water. Time between the nickel strike and the electroforming appeared to be critical, and it was thought that it should be as short as possible.

Bonding Strength Investigation

Table 4 is a list of the bonding strength tests performed. Test blocks were fabricated from 303 and 304 stainless steel. Each block had a 0.5-inch-

TABLE 4. SUMMARY OF ELECTROFORMING TESTS

Test Number	Material (Stainless Steel)	Plating Condition	Burst Pressure (psig)	Bond Quality	Comments
1	304	50 A/ft^2 production plating bath	4600	Excellent	
2	304	25 A/ft^2 production plating bath	500	Poor	
3	304	Same as Test No. 1, but no current reversal in Wood's strike, production bath	500	Poor	
4	304	100 A/ft^2 production bath	1600	Fair	
5	304	Repeat Test No. 1	600	Poor	Failure to repeat invalidates conclusions from Tests No. 1 through 4
6	304	Same as Step No. 1, but no visual inspection during anodic cleaning	2000	Fair	Inconclusive
7	304	Same as Step No. 1, but increased anodic cleaning to 300 A/ft^2 for 3.0 min	1100	Poor	Inconclusive
8	304	Same as Step No. 1, but inserted into electroforming solution with current on	500	Poor	Indicates that length of time turn current on is not a critical parameter
9	304	Same as Step No. 1, but left in electroforming solution for 2 min then turned current on	800	Poor	
10	304	Same as Step No. 1, but PLZT* plating bath used	3600	Excellent	Initial plating current density investigations in both facilities show only that best results are obtained in PLZT lab
11	304	Same as Step No. 1, but electroform current slowly increased	400	Poor	
12	304	Same as Step No. 10, but electroform current slowly increased	4000	Excellent	
13	304	Same as Step No. 1, but electroforming with high current started then reduced	300	Poor	
14	304	PLZT strike PLZT plate	3400	Excellent	Production plating facility can produce good bonds if PLZT lab strike is used
15	304	PLZT strike, production plate	3400	Excellent	
16	303	PLZT strike after 400 A/ft^2 cleaning for 90 sec, PLZT plate	1800	Fair	
17	303	PLZT strike after 400 A/ft^2 cleaning for 3 min, production plate	6000	Excellent	Plating on this unit thicker than on most samples
18	303	3 min 400 A/ft^2 cleaning in Wood's solution, 10 min strike at 50 A/ft^2, production plate	2200	Fair	Thicker strike appears to be of no significant value
19	303	Same as Step No. 18, but plated in PLZT lab	1800	Fair	
20	303	Same as Step No. 17	2600	Fair	400 A/ft^2 cleaning for 3 min does not totally solve problem
21	303	Same as Step No. 17, but olated in PLZT lab	900	Poor	
22	303	New strike, 50 A/ft^2 with no anodic cleaning, PLZT plate	2800	Fair	New 18-ounce nickel per gallon strike was used in 1-gallon beaker
23	303	New "weak" strike, 50 A/ft^2 with no anodic, production plate	4100	Excellent	One gallon of 8-ounce pure nickel per gallon mixture used for these tests to determine if the 32-gallon nickel strike tank should be changed to new "weak" solution. There were no bond failures in this group.
24	303	Same as Step No. 23, but PLZT plate	4000	Excellent	
25	304	New "weak" strike, 90 sec anodic cleaning at 200 A/ft^2, 50 A/ft^2 strike, production plate	4100	Excellent	
26	303	Same as Step No. 23, but PLZT plate	4000	Excellent	
27	304	Same as Step No. 23, but with 304 stainless steel	5300	Excellent	
28	303	Same as Step No. 26, but 30 sec delay at each step	3800	Excellent	
29	304	Same as Step No.27, but 30 sec delay at each step	5600	Excellent	
30	303	Same as Step No. 23 in production strike, production plate	4600	Excellent	New production strike bath using 8-ounce nickel per gallon. Same process for 303 and 304 stainless steel materials
31	304	Same as Step No. 30, but 304 stainless steel and PLZT plate	5600	Excellent	
32	303	Same as Step No. 30, but strike at 100 A/ft^2 rather than a 50 A/ft^2	5200	Excellent	
33	304	Same as Step No. 31, but 100 A/ft^2 strike	5000	Excellent	
34	303	Same as Step No. 30, but strike at 25 A/ft^2	5000	Excellent	
35	303 Selenium	Same as Step No. 30, but 303, stainless steel with selenium used	200	Poor	This series of tests investigated 303 stainless steel with selenium. Test No. 37 was used to determine if bath had changed its characteristics.
36	303 Selenium	Same as Step No. 35, but plate in PLZT lab	400	Poor	
37	304	Repeat, 50 A/ft^2 production strike (weak), no anodic production plate	6400	Excellent	
38	303 Sulfur	Sulfuric acid clean, no strike, PLZT plate	300	Poor	
39	303 Selenium	Sulfuric acid clean, no strike, production plate	100	Poor	
40	303 Sulfur	Sulfuric acid clean plus 50 A/ft^2 cathodic in H_2SO_4, no strike	4700	Excellent	
41	303 Selenium	H_2SO4 clean plus 50 A/ft^2 cathodic in H_2SO_4, no strike	3700	Excellent	
42	303 Sulfur	H_2SO_4 clean plus 50 A/ft^2 cathodic in clean H_2SO_4	4800	Excellent	
43	303 Selenium	H_2SO_4 clean plus 50 A/ft^2 cathodic in clean H_2SO_4	1100	Poor	

* PLZT lab is the designation for the standard Honeywell plating facility.

diameter hole in the top and provisions for a hydraulic fitting below, such that the plated sample could be pressurized and the quantitative data on the bond strength could be measured.

Current density was the first parameter to be investigated using the production plating facility. Test 1 demonstrated an excellent bond at 50 A/ft^2 activation current. Tests 2 and 4 fallaciously indicated that current density was critical, as both higher and lower values produced poor bonds. Test 3 indicated that the current reversal in the Wood's nickel bath was needed, as a poor bond resulted when this step was eliminated. Test 5, which was a repetition of the Test 1 conditions, resulted in a very poor bond, indicating that some parameter other than current density was a major contributor to bond strength.

Tests 6 through 11 investigated the general theory that the length of time between electroforming steps was critical. Results were unsatisfactory. Test 10, which was conducted at the same time as Test 11, indicated that the production electroforming bath was unsatisfactory and that the good bond on Test 1 was an unusual case.

Tests 12 through 15 demonstrated that the production line Wood's nickel bath was part of the problem and that the production line electroforming bath was satisfactory. In Test 15, the Wood's nickel strike was accomplished in the standard Honeywell Facility. The sample was placed in a beaker of Wood's nickel and carried to the production plating line where it was electroformed. This test proved that the time between the strike and plating is not critical.

Bonds on 303 stainless steel were marginal even when using the established process. Failures always occurred along the bond rather than causing a rupture of the electroforming, as was the case when the 304 stainless bonded properly. In Tests 16 through 21, the cleaning and Wood's nickel strike processes were varied to improve the bond strength. Only Test 17 provided an excellent bond, but the process was not repeatable.

With 303 stainless steel,the anodic cleaning step in the Wood's nickel bath was the most critical. In general, the sample would turn dark at the start and then clear if the current density was increased to 300 A/ft^2 or 400 A/ft^2 for a period of 90 seconds or longer. It is suspected that this film was preventing a good bond and that it might exist even when it is not visible to the naked eye. Variations in this "invisible" film is one explanation for the lack of repeatability in plating bond strength on 303 stainless steel. Process investigations were directed to eliminate the anodic cleaning in the Wood's bath due to its unpredictable nature. Anodic cleaning in the sulfuric acid bath did not produce this residue.

Previous testing showed that the production Wood's bath was unsatisfactory; this led to the speculation that the standard bath could also be marginal after several years use. A new one-gallon batch (18 ounces of nickel per gallon) of Wood's nickel solution was prepared in a beaker, and Test 22 was conducted in this small quantity of unadulterated solution. (Anodic cleaning in the Wood's bath adds stainless steel to the solution, and this could be a contaminant.) Sample 22 was able to withstand 2,800 psi, indicating that it would be satisfactory for the rate sensor application. A failure at the bond rather than a rupture of the electroforming indicated that the process was still marginal.

Reducing the strength of the Wood's nickel strike from 18 ounces of pure nickel per gallon to 8 ounces per gallon proved to be a major factor in the improvement of the bond strength. Tests 23 through 29 were conducted with a one-gallon sample of the low-concentrate solution. All samples proved to be good even with delays between the electroforming steps. This series of tests proved that many of the parameters thought to be critical were not critical.

The 32-gallon production tank was changed to the new low-concentration Wood's nickel strike, and Tests 30 through 34 were performed. This series of tests showed that the revised process provides good bonds with 303 or 304 stainless steel and that current density is not a critical parameter.

Final Production Process

Steps in the electroforming process are now the same for 304 and 303 stainless steel with the 8-ounce-per-gallon Wood's nickel solution. These steps are:

1. Parts are cleaned in a 10-percent sulfuric acid bath for 15 minutes.

2. Activation is accomplished at a current density of 50 A/ft^2 in the Wood's nickel bath (anodic cleaning in the Wood's bath was eliminated).

3. Parts are plated in the Barret sulfamate nickel electroforming solution.

Appendix D is a detailed electroforming process specification.

Process Limitation

Rate sensor pickoffs present the only potential problem with the final electroforming process when the 303 stainless includes a high concentration of selenium. Poor test results were obtained (Tests 35 and 36) when a 303 stainless steel test block with selenium was electroformed using the final process. Eliminating the Wood's nickel strike completely also resulted in poor bonds (Tests 38 and 39). Performing the cathodic operation in the sulfuric acid cleaning bath rather than the Wood's nickel bath gave excellent results, and it was speculated that the contaminants in the cleaning solution may have helped. When the cathodic operation was done in clean sulfuric acid (Tests 42 and 43), only the 303 stainless steel with sulfur resulted in a good bond. Tests 40 through 43 indicated that an optimum process might eliminate the Wood's nickel bath completely and use a very weak (e.g., 0.5 ounce of nickel per gallon) sulfuric acid solution for the cathodic operation. Optimizing this process would require substantial development effort.

An analysis of several 303 samples is shown in Table 5. When ordering the material, the major type of additives can be specified.

TABLE 5. ANALYSIS OF 303 SAMPLES

303 Sample	Sulfur (pct)	Selenium (pct)
Rate Sensor Baseplate (Poor Bond with Original Process)	0.30	0.110
Rate Sensor Baseplate (Fair Bond with Original Process)	0.30	0.060
Test Block (303 with Sulfur)	0.30	0.067
Test Block (303 with Selenium)	0.01	0.290

The rate sensor baseplates being used in the production run will closely resemble the 303 stainless steel with sulfur that was used in the testing. Probability of success is very high using the revised process on the rate sensor baseplates, and more detailed investigations are not warranted at this time. A rate sensor baseplate that previously had a poor bond was replated with the revised process, and the bond was excellent. All production electroforming will use the process described in Appendix D.

Current Robbers

Plastic shielding was initially used around the edges of the IC during the plating process to obtain a more uniform current distribution and to prevent excessive nickel buildup around the baseplate edges. One disadvantage of the shields is that they impede the solution's circulation around the edges of the circuit and allow air bubbles to gather, which can result in a void in the plating. A second disadvantage is that the shields did only a marginal job of preventing nickel buildup at the outer edges. The shields were replaced with current robbers (wire that is plated along with the circuit) around the outside of the circuits, and a significant improvement in plating distribution was observed.

LOT TWO PERFORMANCE SUMMARY

IC modifications were accomplished using existing channels in the mold wherever practical. Rate sensor signals passed through R3 and R26 (previously preamplifier feedback resistors) as shown in Figure 16 (see page 50). Resistor "blanks", used in place of R3 and R26 to redirect the rate sensor signal around the eliminated first stage (see page 36), proved to be too restrictive, causing the indicated gain of the IC 818 rate sensor amplifier to be only 1.8 psid/psid. Later, when IC's 822 and 823 were tested, the resistor blanks were modified to be less restrictive, and the rate sensor amplifier gain was increased to 3.2 psid/psid (Table 6). Through-rate gain on IC 818 was also low, confirming that there was a loss across R3 and R26. Output cascade gains were very consistent for all three IC's.

TABLE 6. CHANGE IN GAIN WITH IC MODIFICATIONS

I.C. No.	Rate Sensor Amplifier Gain (psid/psid)	PID Amplifier Gain (psid/psid)	Through-Rate Gain (psid/deg/sec)	Output Cascade Gain (psid/psid)
818	1.8	3.5	3.8	53.0
822	3.1	4.1	7.2	54.0
823	3.2	3.7	7.3	53.5

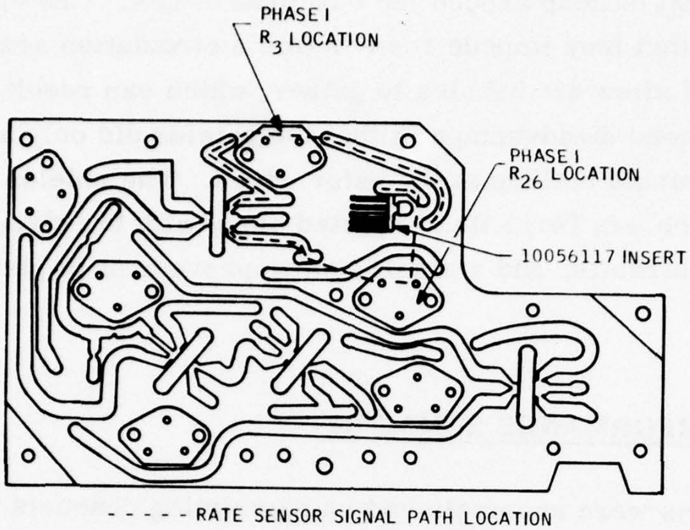


Figure 16. Lot Two Circuit Sketch.

Performance of the Lot two rate sensors is shown in Figures 17, 18, and 19. The flow-loaded gain is less than half the dead-ended gain, which is similar to that experienced during actual operation. The gain of the long-stem pickoff may be slightly higher than that of the short-stem pickoffs in Lot one. Null offset appears to be about twice as great with the long-stem pickoff, but available data is not sufficient to prove this relationship. Gains on these curves were revised upward by about 10 percent as a result of later test facility calibration.

A parameter variation experiment was performed on PID during fabrication of Lot two. Analysis indicated that the width of the metering slot is the most critical parameter affecting PID gain. PID sleeves were selected with different slot widths to evaluate this critical parameter. Test fixture loads were also increased by changing the orifices to 0.022 inch in diameter to reflect the lower input impedance of the modified PID amplifier. Test results are presented in Figure 20 and in Table 7.

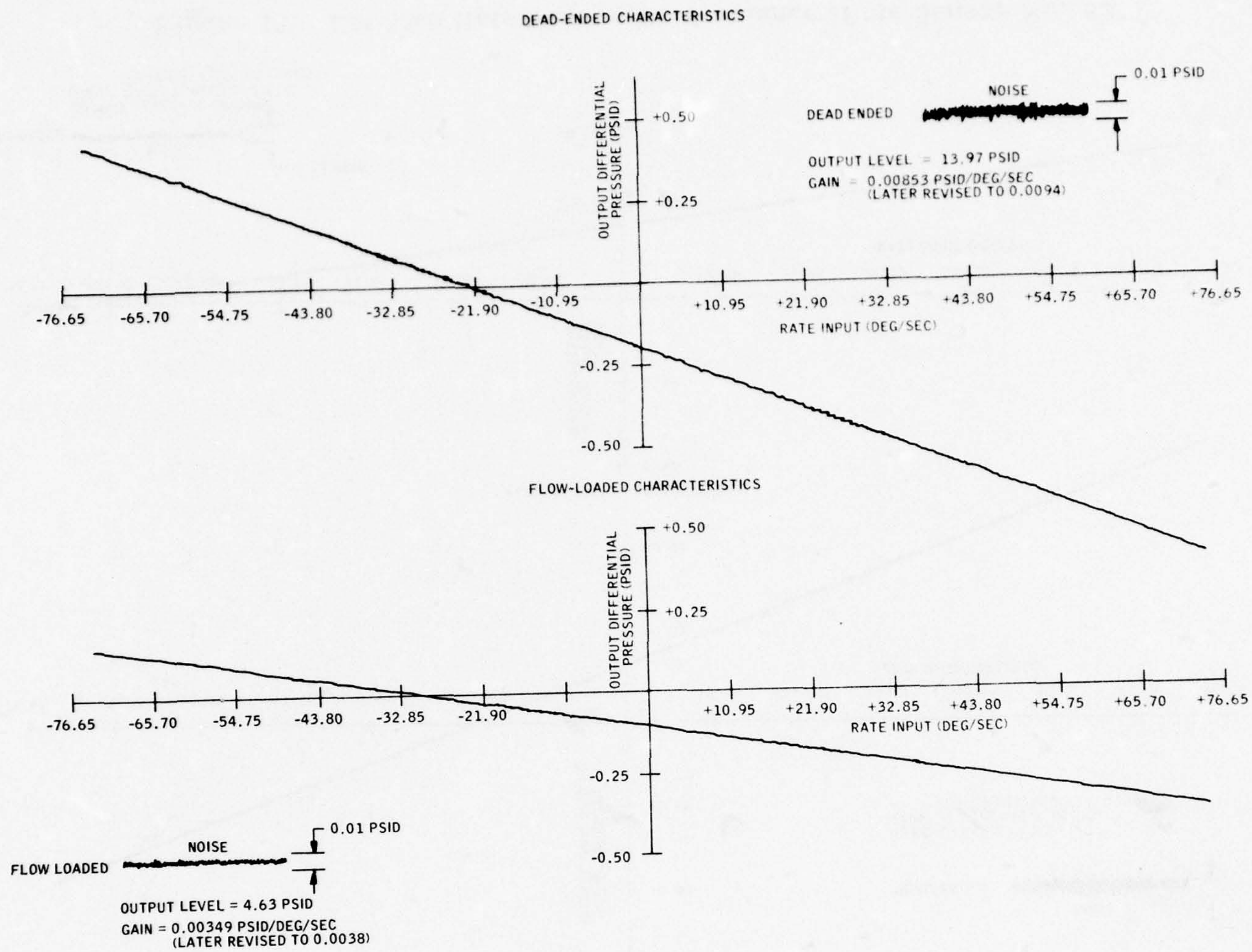


Figure 17. Lot Two Rate Sensor Performance (Rate Sensor No. 819).

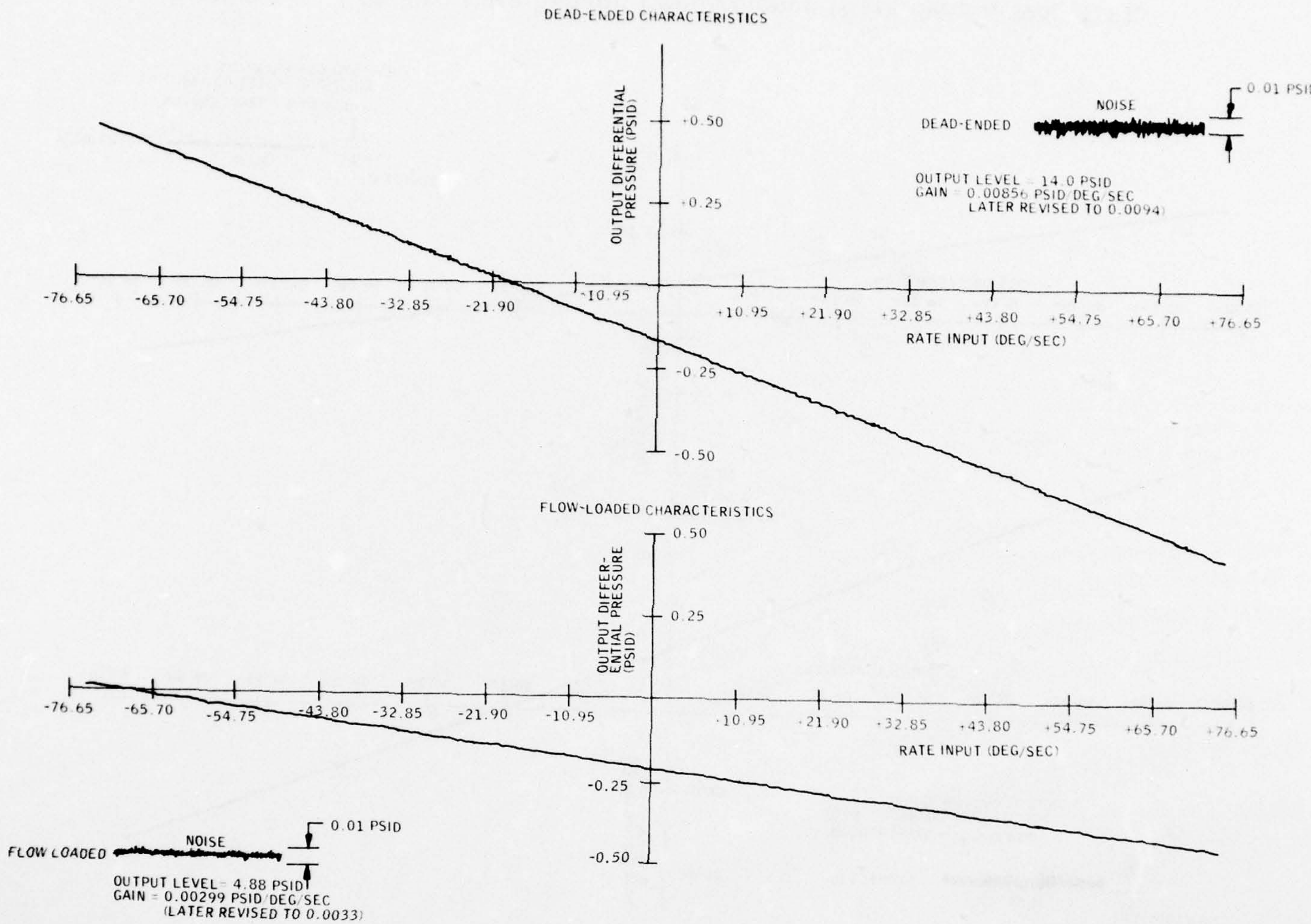


Figure 18. Lot Two Rate Sensor Performance (Rate Sensor No. 821)

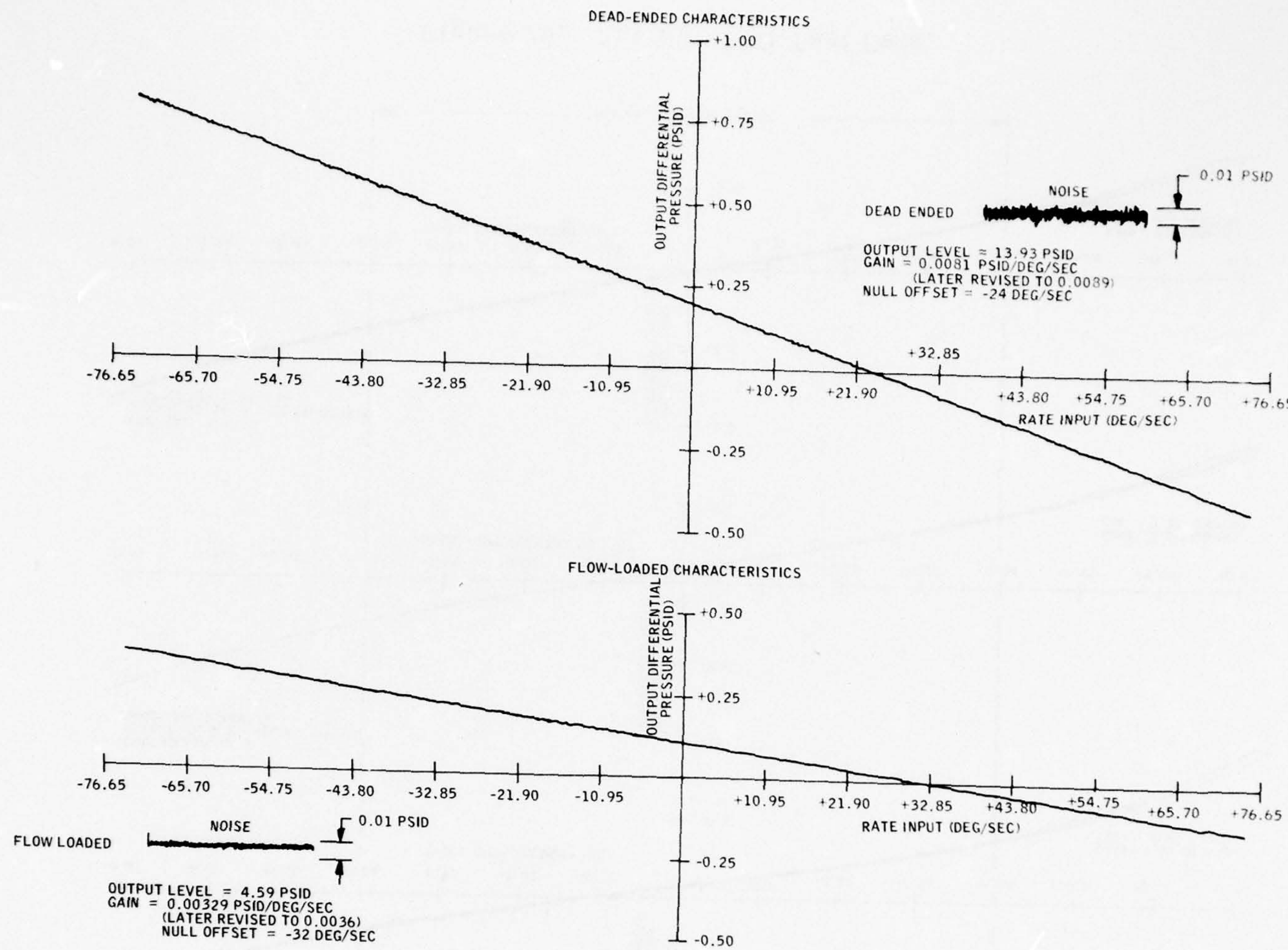


Figure 19. Lot Two Rate Sensor Performance (Rate Sensor No. 821).

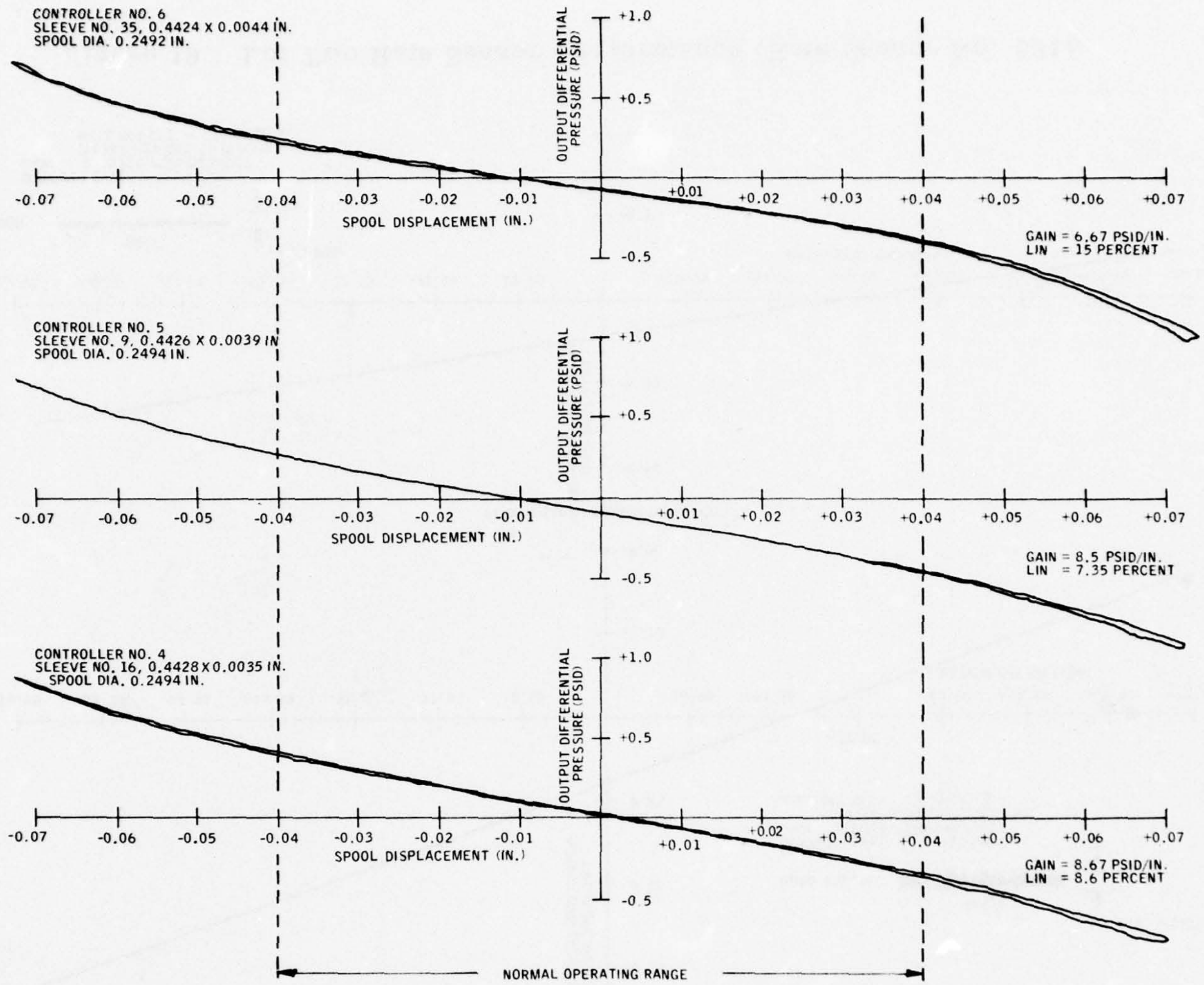


Figure 20. Lot Two PID Test Data.

TABLE 7. LOT TWO PID TEST DATA

Controller	Sleeve No.	Slot Length (in.)	Slot Width (in.)	Spool Diameter (in.)	Gain (psid/in.)	Linearity (pct)
4	16	0.4428	0.0035	0.2494	8.67	8.6
5	9	0.4426	0.0039	0.2494	8.5	7.35
6	35	0.4424	0.0044	0.2492	6.67	15.0

Gain remained within reasonable limits over the complete range of slot widths from 0.0035 inch to 0.0044 inch, which encompasses all PID sleeves manufactured for this program. Spools were all either 0.2494 inch or 0.2492 inch in diameter. Production units will use 0.2494-inch-diameter spools. This small change in spool diameter significantly affects the gain.

PID requirements have a gain of 7.8 ± 1.2 psi/in. and a linearity of ±20 percent over the ±0.04 inch input. The PID specification was revised to be compatible with the revised test procedure. Note that the hysterisis has been nearly eliminated. Improved impedance matching with the PID amplifier, improvements in the component test fixture, and improved test procedures resulted in relatively consistent PID performance. Linearity has also greatly improved.

Test results of the Lot two system show an improved performance over that obtained during Lot one testing. Gain was low due to excessive feedback in the existing feedback resistors. Reduced-gain feedback resistors will permit satisfactory system gains. Overall system performance is given in Table 8, and system gain as a function of temperature is shown in Figure 21. Reducing the feedback will increase system gain, but gain change with temperature will be somewhat greater than this extremely consistent characteristic. With the exception of low gain, system response as shown in Figures 22 and 23 is within specification limits.

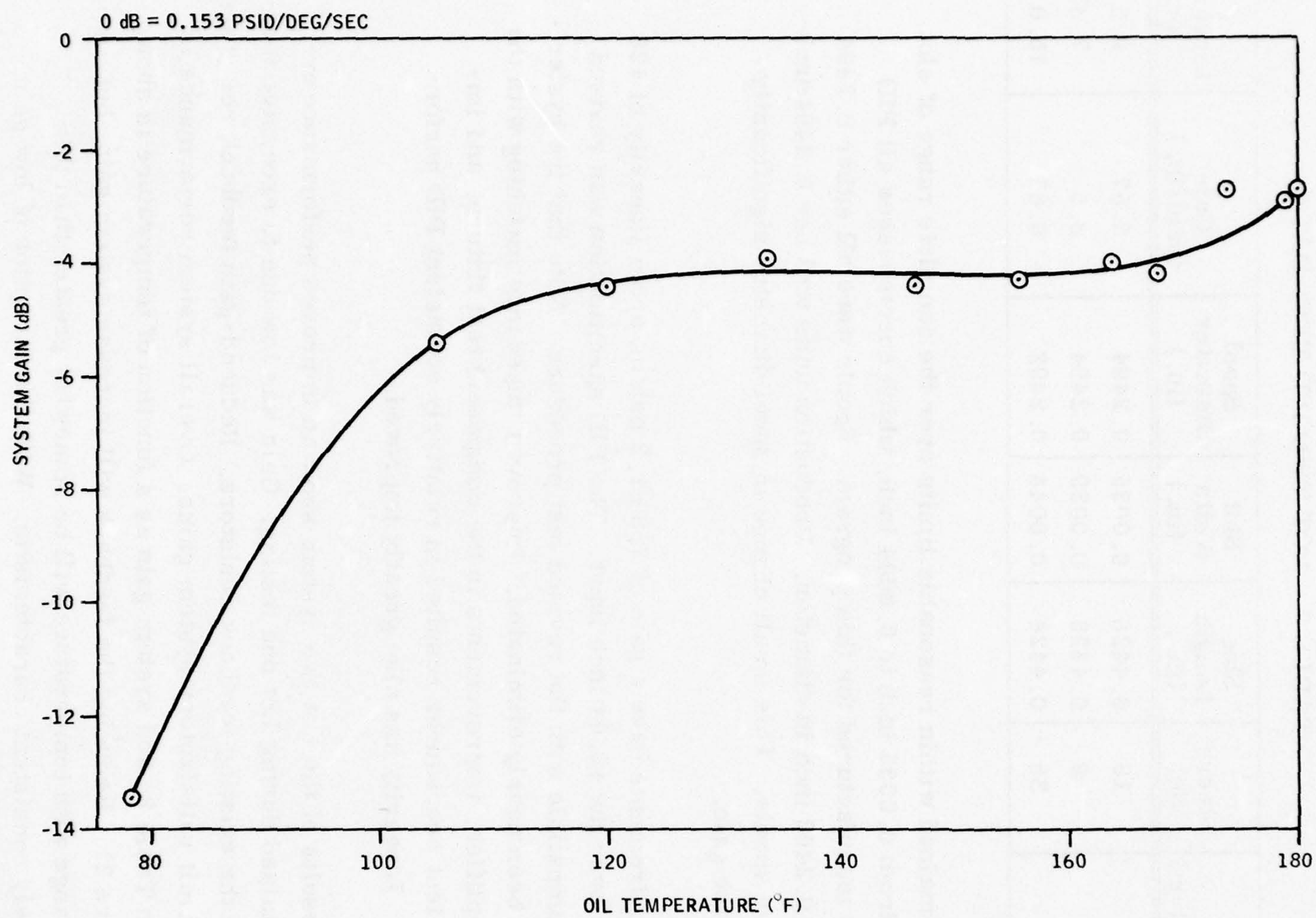


Figure 21. Lot Two System Rate Gain as a Function of Fluid Temperature.

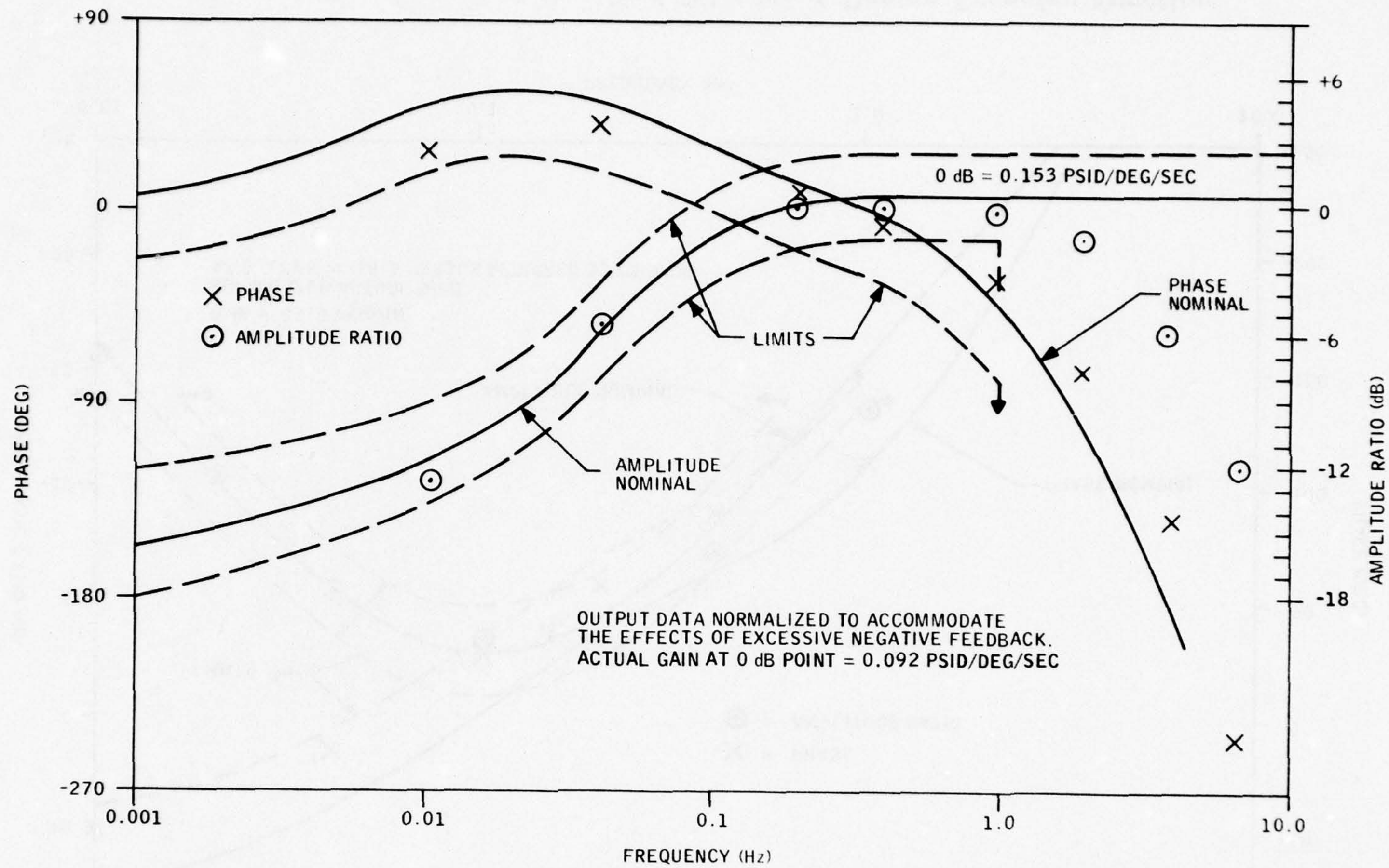


Figure 22. Lot Two System Normalized Rate Transfer Function.

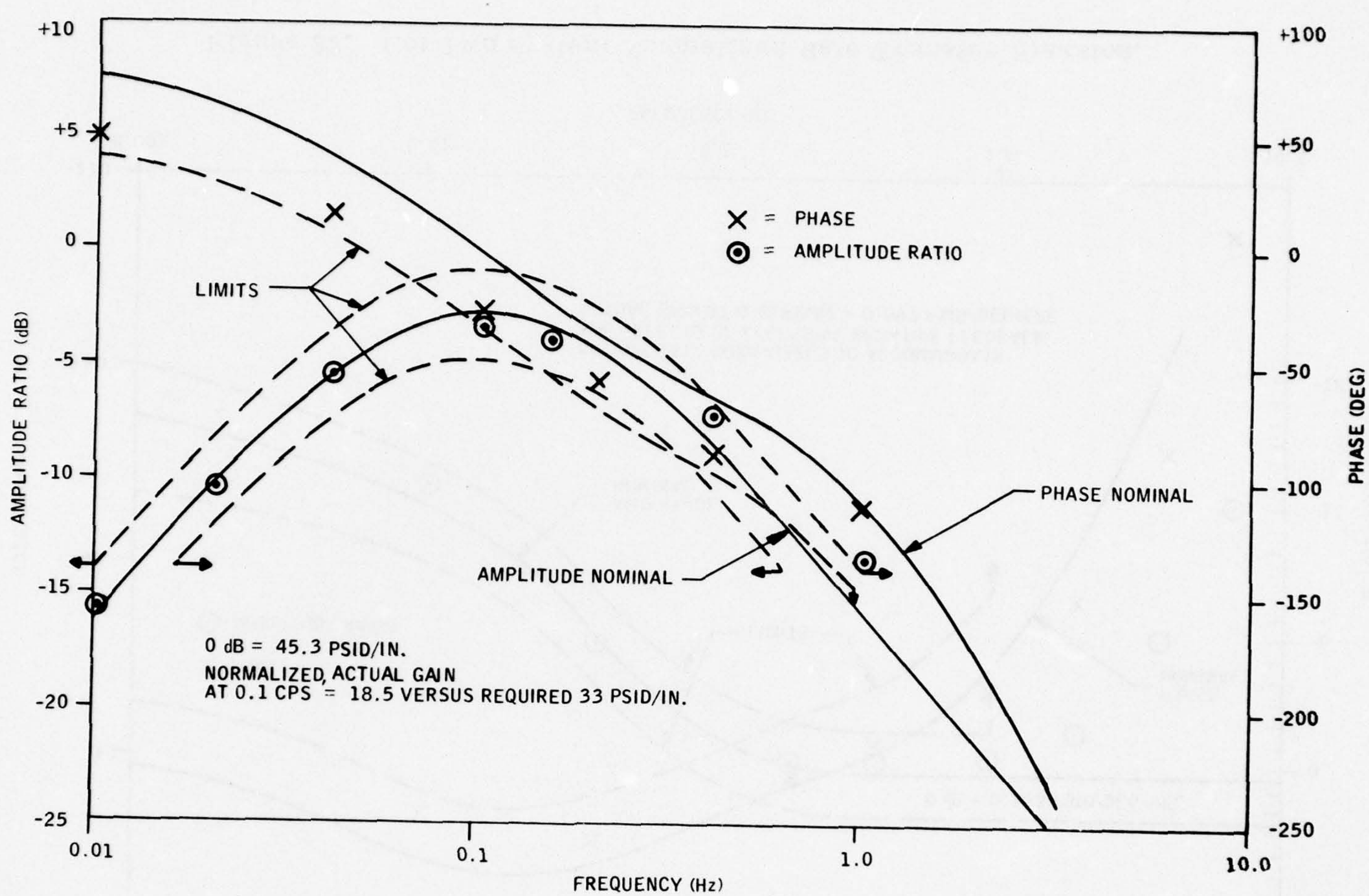


Figure 23. Lot Two System Normalized Pilot Input Device Transfer Function.

TABLE 8. LOT TWO SYSTEM TEST RESULTS

Parameter	120°F Requirement	Test Results
High-Pass Rate Gain	0.153±0.019 psid/deg/sec	0.092 psid/deg/sec
Through-Rate Gain	0.033±0.005 psid/deg/sec	0.019 psid/deg/sec
PID Gain	33.4±4.2 psid/in.	19.5 psid/in.
Noise (120°F)	±0.2 psid	±0.02 psid
Noise (180°F)	---	±0.1 psid
Offset	±0.4 psid	-0.3 psid

SECTION IV

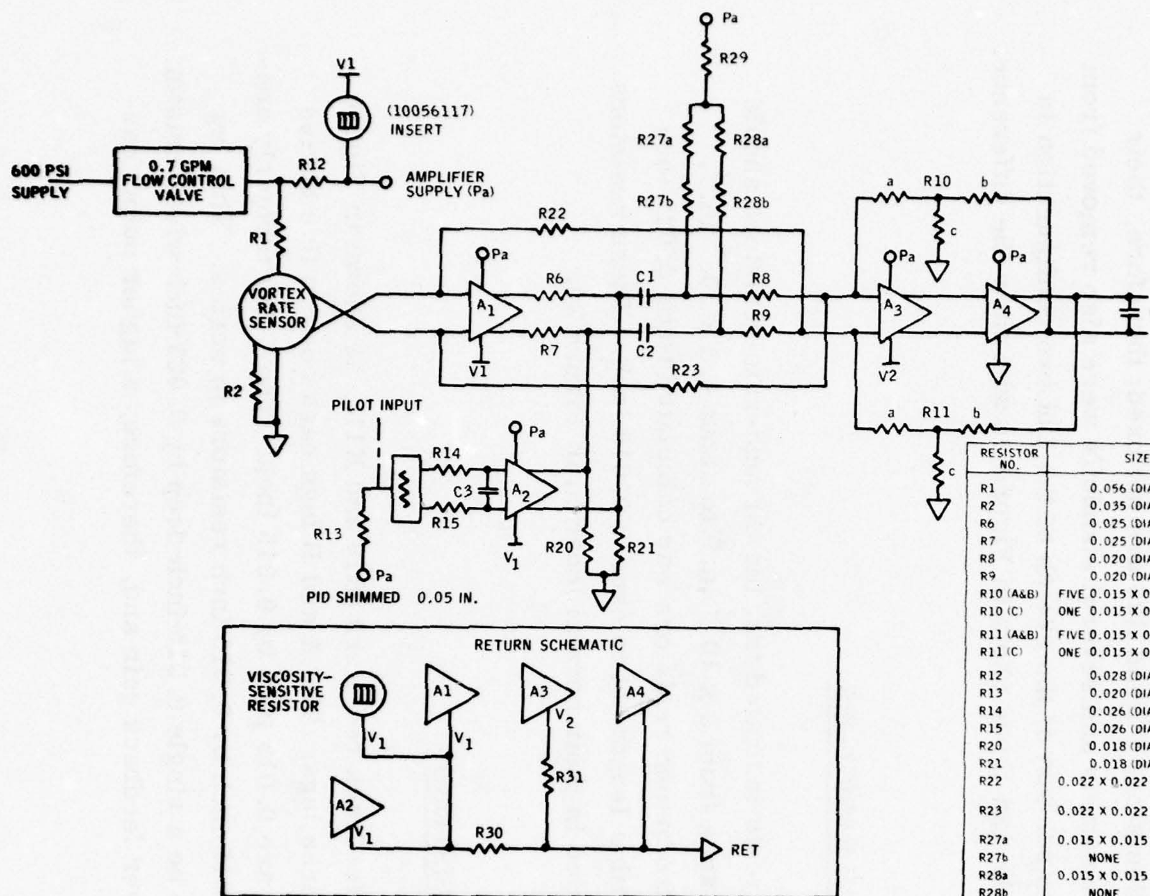
LOT THREE

SYSTEM CONFIGURATION SUMMARY

Changes for Lot three were:

- Extensive modification to channels between rate sensor input and first-stage amplifier
- Electroforming of through-rate resistors on their separate blocks. A new mold was fabricated.
- Modification of the mold for the output cascade feedback resistors to provide lower feedback gain
- Modification of the PID lever to provide better clamping
- Modification of the controller housing to provide test points for system calibration
- Use of the revised electroforming process

Only three systems were required in Lot three; however, five sets of hardware were electroformed. This was necessary to provide current density distributions consistent with those experienced during later production runs. A schematic of the Lot three system is shown in Figure 24.



RESISTOR NO.	SIZE (IN.)	CONFIGURATION
R1	0.056 (DIA.)	DRILLED IN HOUSING
R2	0.035 (DIA.)	REPLACEABLE
R6	0.025 (DIA.)	REPLACEABLE
R7	0.025 (DIA.)	REPLACEABLE
R8	0.020 (DIA.)	REPLACEABLE
R9	0.020 (DIA.)	REPLACEABLE
R10 (A&B)	FIVE 0.015 X 0.015 IN SERIES	THREE BRANCH NETWORK ELECTROFORMED AS A BOLT ON ASSEMBLY
R10 (C)	ONE 0.015 X 0.023	
R11 (A&B)	FIVE 0.015 X 0.015 IN SERIES	THREE BRANCH NETWORK ELECTROFORMED AS A BOLT ON ASSEMBLY
R11 (C)	ONE 0.015 X 0.023	
R12	0.028 (DIA.)	REPLACEABLE
R13	0.020 (DIA.)	REPLACEABLE
R14	0.026 (DIA.)	REPLACEABLE
R15	0.026 (DIA.)	REPLACEABLE
R20	0.018 (DIA.)	REPLACEABLE
R21	0.018 (DIA.)	REPLACEABLE
R22	0.022 X 0.022	ELECTROFORMED BOLT ON ASSEMBLY
R23	0.022 X 0.022	ELECTROFORMED BOLT ON ASSEMBLY
R27a	0.015 X 0.015 X 0.070 LONG	ELECTROFORMED ON IC
R27b	NONE	REPLACEABLE
R28a	0.015 X 0.015 X 0.070 LONG	ELECTROFORMED ON IC
R28b	NONE	REPLACEABLE
R29	0.015 X 0.015 X 0.020 LONG	ELECTROFORMED ON IC
R30	0.047 X 0.050	ELECTROFORMED ON IC
R31	0.027 X 0.027	ELECTROFORMED ON IC

Figure 24. Lot Three System Schematic.

IC CHANNEL MODIFICATIONS

Temporary mold modifications for Lot two resulted in long, irregular pathways between the rate sensor input and the first-stage amplifier. When testing proved the Lot two modifications to be satisfactory, they were made permanent. The configuration of these channels is shown in Figure 25. Resistors R3 and R26 are not used; therefore, their communicating channels and several standoffs were also removed from the mold. A comparison of the sketch of the Lot two configuration in Figure 16 with the Lot three photo in Figure 25 will show the difference.

THROUGH-RATE RESISTORS

Lot two system tests indicated that the through-rate resistors should be increased in area from 2×10^{-4} in.^{2} to about 4.8×10^{-4} in.^{2}. Size of the electroformed resistors was calculated to be 0.022 inch by 0.022 inch with a length not to exceed 0.015 inch. These resistors are shown mounted in their normal location in Figure 25.

FEEDBACK RESISTORS

Output cascade feedback resistors (R10 and R11), as shown in Figure 24, consist of three legs. The A and B legs each contain five series restrictors that are 0.015 inch by 0.015 inch. The C leg formerly consisted of two 0.015 inch by 0.015 inch resistors in series. This leg was modified to be a single 0.015-inch-deep by 0.023-inch-wide resistor to provide a lower feedback gain and, therefore, a higher output cascade gain.

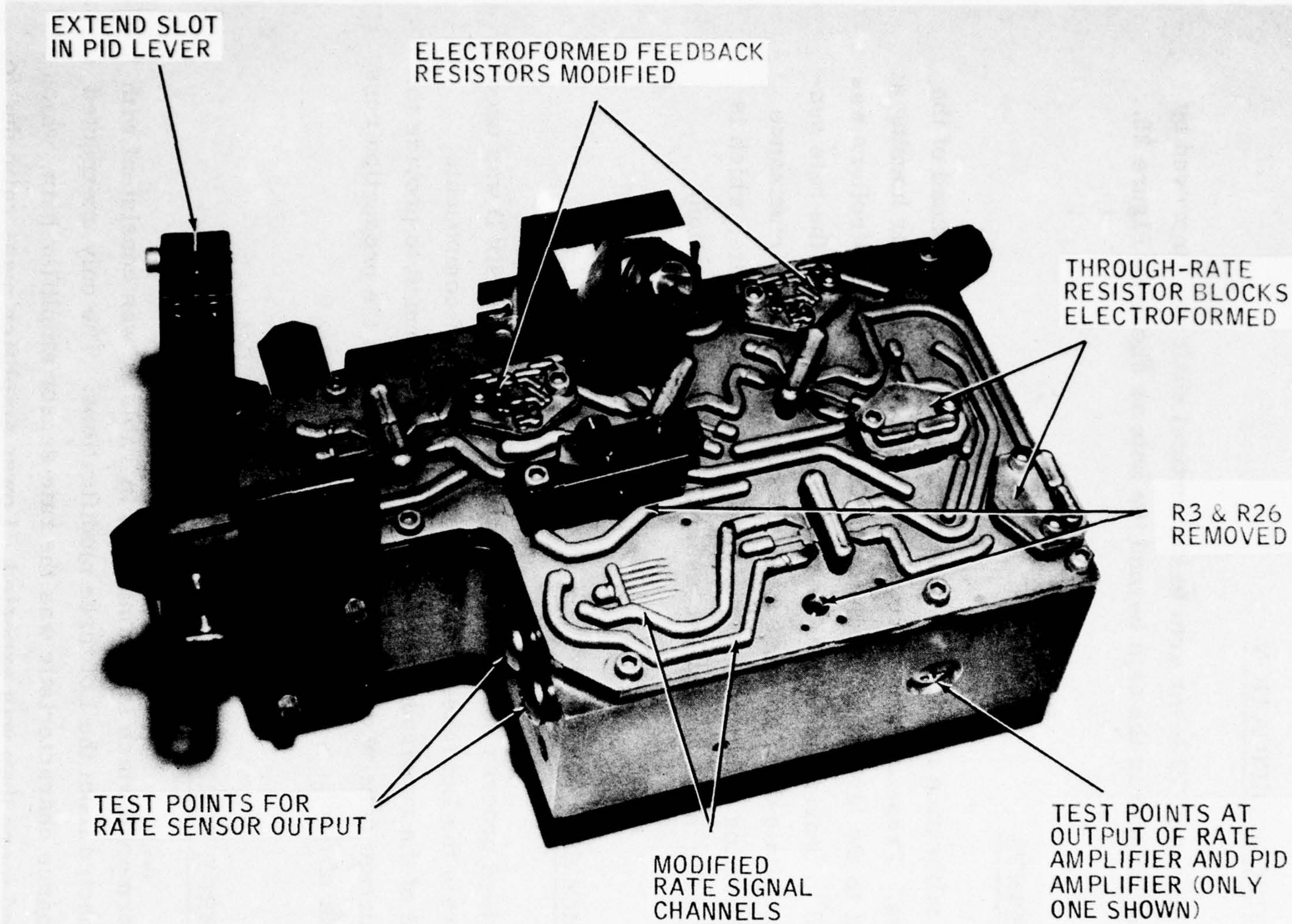


Figure 25. Modified Integrated Circuit.

PID LEVER MODIFICATION

Clamping of the PID lever arm to its vertical shaft was improved by extending the slot in the arm beyond the hole as shown in Figure 25.

TEST POINTS

Proper calibration requires a measurement of the signal ahead of the high pass. Pressure taps were designed into the controller housing at the input to the high-pass capacitors. Only one of the controllers was modified to provide additional test points at the output of the rate sensor to facilitate detailed measurements of rate sensor performance under operating conditions. This second set of test points, which is visible in Figure 25, is not necessary for system calibration.

ECW PROCESS

The revised process described in Section III and Appendix D was used to fabricate the Lot three components. Five sets of components (instead of the required three sets) were electroformed to provide the same current density distribution that will exist in the production runs (four lots of five).

LOT THREE PERFORMANCE SUMMARY

IC performance, which is summarized in Table 9, was consistent with that expected from the Lot three modifications. The only unexpected performance characteristic was the rate sensor amplifier gain, which improved more than was expected. Lower amplifier mass ratio due to

TABLE 9. SUMMARY OF LOT THREE PERFORMANCE

I. C. No.	Rate Sensor Amplifier Gain (psid/psid)	PID Amplifier Gain (psid/ psid)	Through-Rate Gain (psid/deg/sec)	Output Cascade Gain (psid/psid)	Output Cascade With Feedback (psid/psid)
850	4.3	3.3	11.8	59.3	9.3
851	3.6	3.5	11.8	51.4	9.0
853	4.0	3.4	11.5	48.6	9.2

larger through-rate resistors is one explanation. Through-rate gain also increased because of the larger area of the electroformed through-rate resistors. Appendix C presents the final IC specification.

Lot three rate sensor performance is shown in Figures 26 through 28. Output loads were reversed to show that the test fixture was not the cause of flow-loaded null offset. Gains are consistent with system requirements. Gains were later proven to be higher by 10 percent as a result of facility recalibration. (Appendix B presents the final rate sensor specification.)

Lot three PID's were selected to be identical in performance; however, their performance differences were significant. All PID hardware was fabricated as a single lot at the beginning of this program; only the electroformed hardware was to be fabricated in separate lots. Quality of workmanship, specifically surface finish on the spool inner diameter, was relatively poor and was one cause for a substantial variation in PID performance. Drawings were modified to require a number 16 surface finish in this bore; however, this will not apply to the Phase III production hardware as the parts have already been fabricated. Results of Lot three PID tests are given in Table 10. Gain on two of the units is slightly high. Appendix A presents the final PID specification.

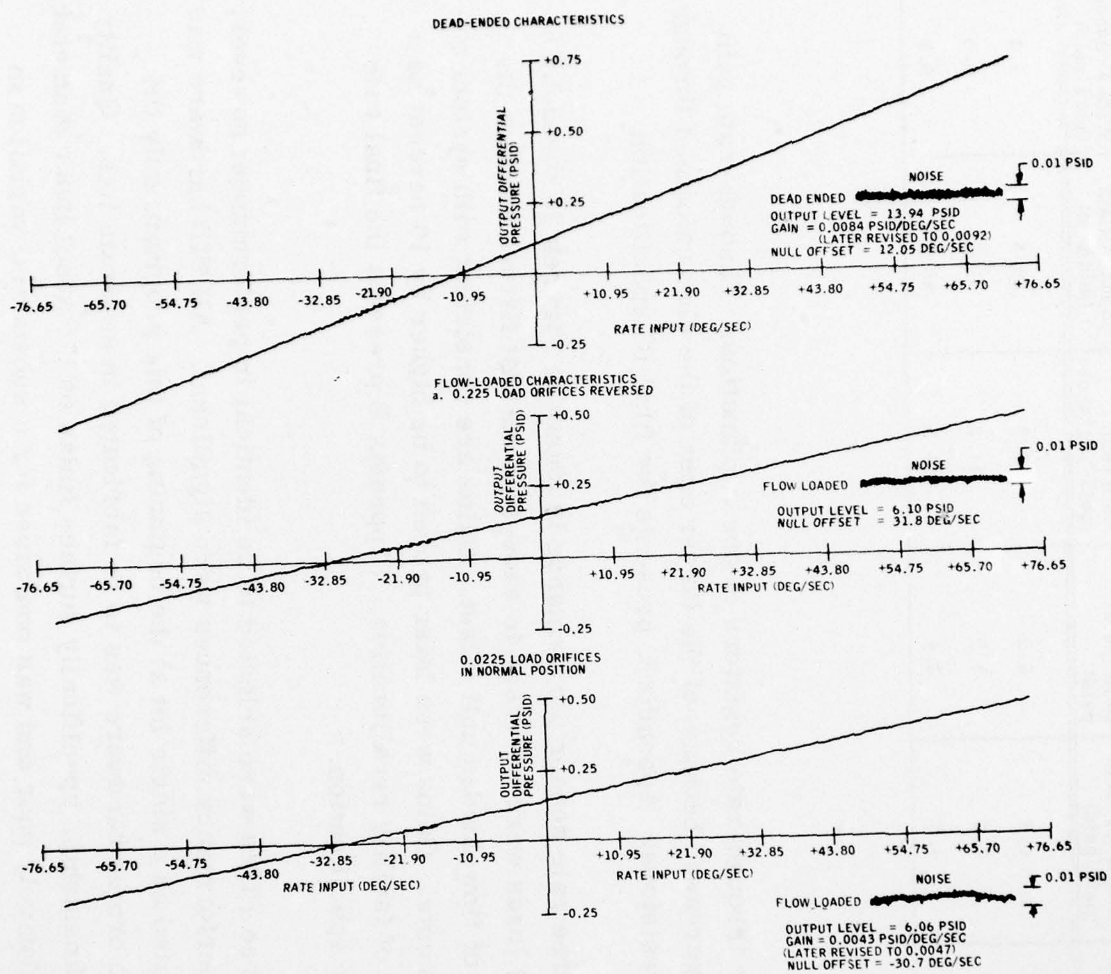


Figure 26. Lot Three Rate Sensor Performance (Rate Sensor No. 830).

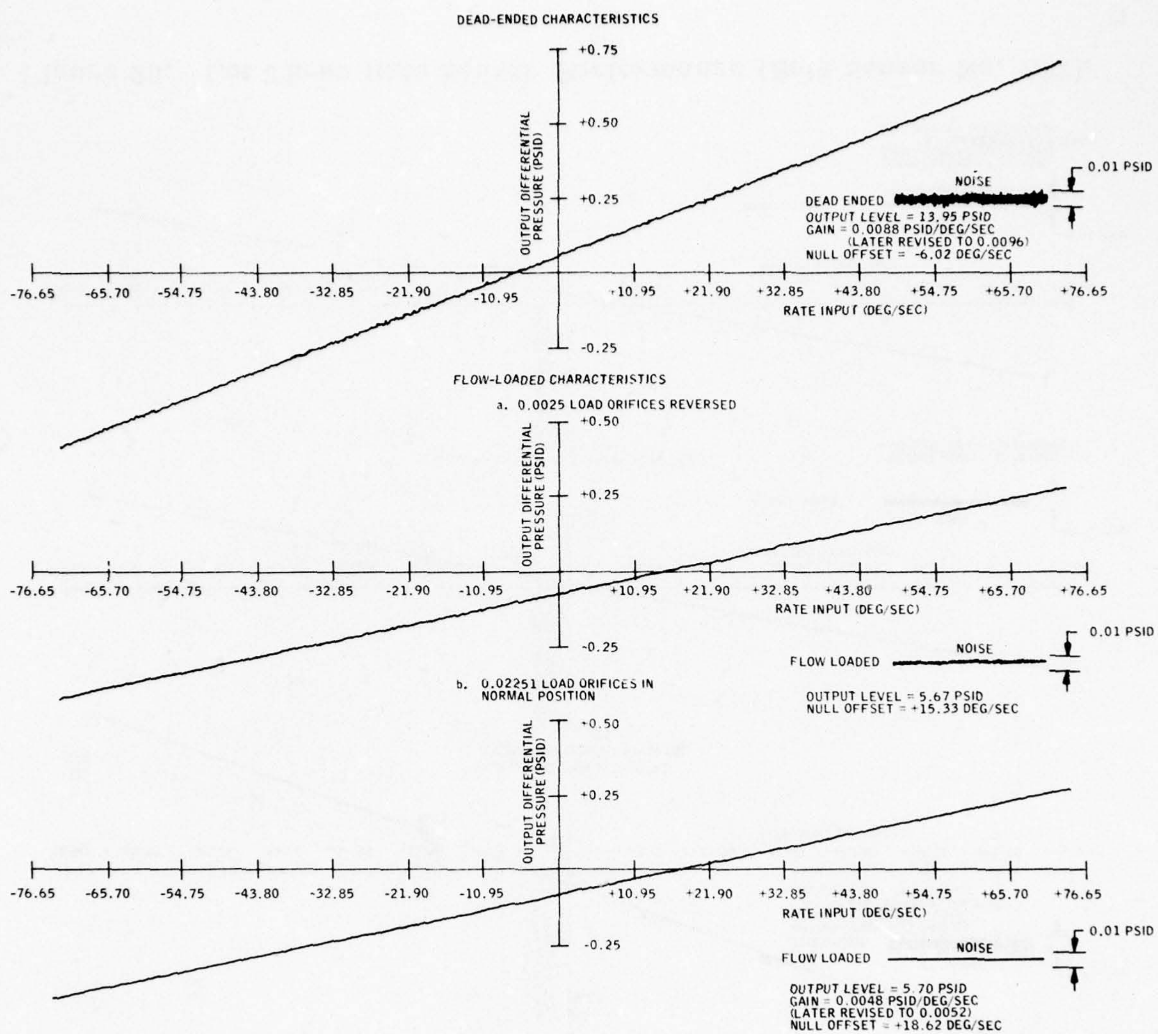


Figure 27. Lot Three Rate Sensor Performance (Rate Sensor No. 831).

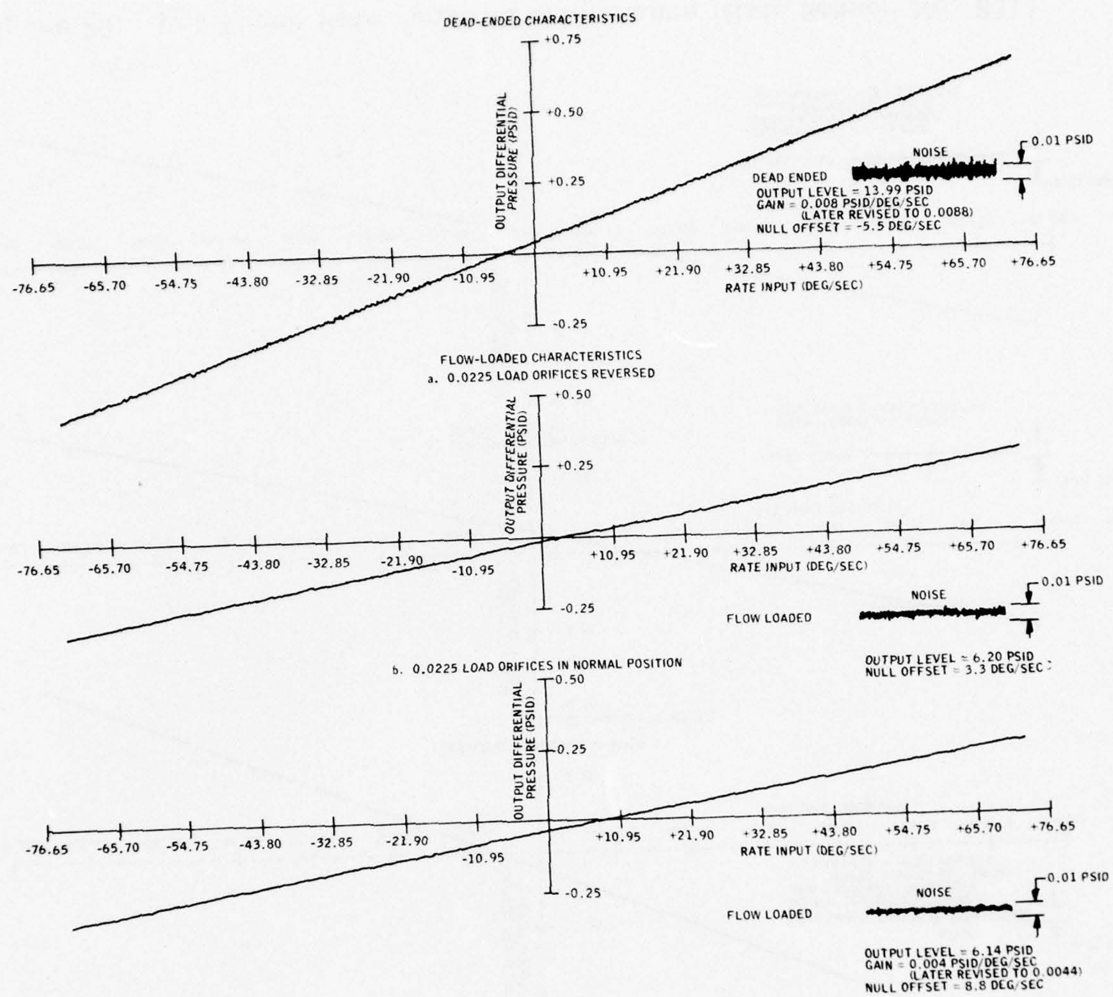


Figure 28. Lot Three Rate Sensor Performance (Rate Sensor No. 832).

TABLE 10. SUMMARY OF LOT THREE PID PERFORMANCE TESTS

	Sleeve Data				Spool Data	Performance	
Controller	S/N	Slot Width (in.)	Slot Length (in.)	Bore Diameter (in.)	Diameter (in.)	Gain (psid/in.)	Linearity (pct)
7	1	0.0039	0.4484	Data Not Available	0.2494	9.38	23.3
8	18	0.0039	0.4463		0.2494	7.56	11.2
9	28	0.0039	0.4471		0.2494	9.69	9.2

The Lot three system was calibrated to obtain the gains given in Table 11.

TABLE 11. LOT THREE SYSTEM GAINS

Parameter	120°F Requirement	Test Results
High-Pass Rate Gain	0.153 ± 0.019 psid/deg/sec	0.157 psid/deg/sec
Through-Rate Gain	0.033 ± 0.005 psid/deg/sec	0.03 psid/deg/sec
PID Gain	33.4 ± 4.2 psid/in.	33 psid/in.
Noise (120°F)	± 0.2 psid	± 0.05 psid
Noise (178°F)		± 0.25 psid
Offset	± 0.4 psid	± 0.1 psid

Frequency response for the system is shown in Figures 29 and 30. Because all gains were within specification limits, it was not necessary to normalize either of the curves shown. Gain as a function of temperature is shown in Figure 31. A second IC was installed in place of the first IC, and the tests were repeated with nearly identical results. Variation in gain with temperature is greater than it was for Lot two, and it appears that the reduced feedback on the output cascade is the

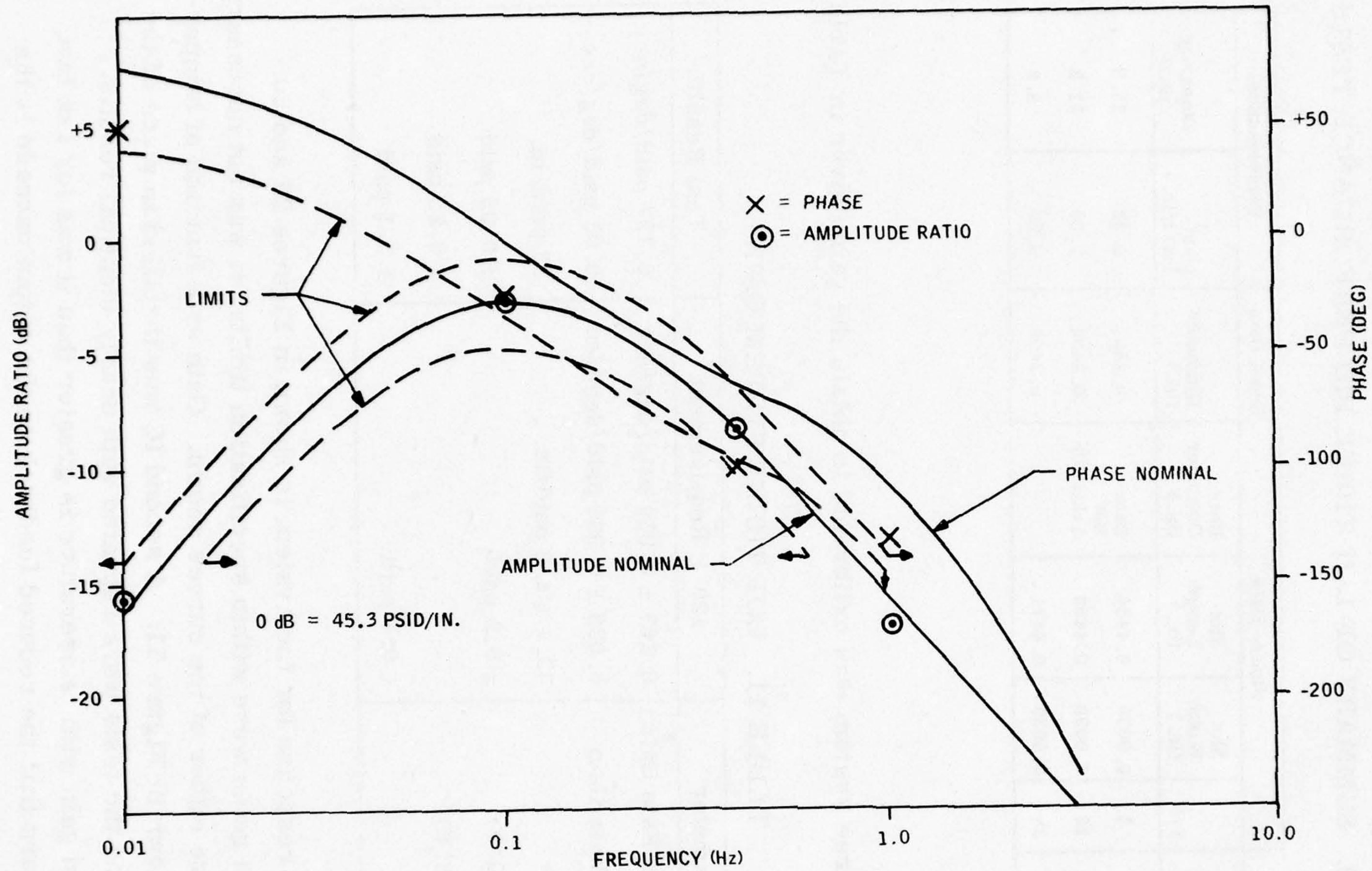


Figure 29. Lot Three Pilot Input Device Frequency Response.

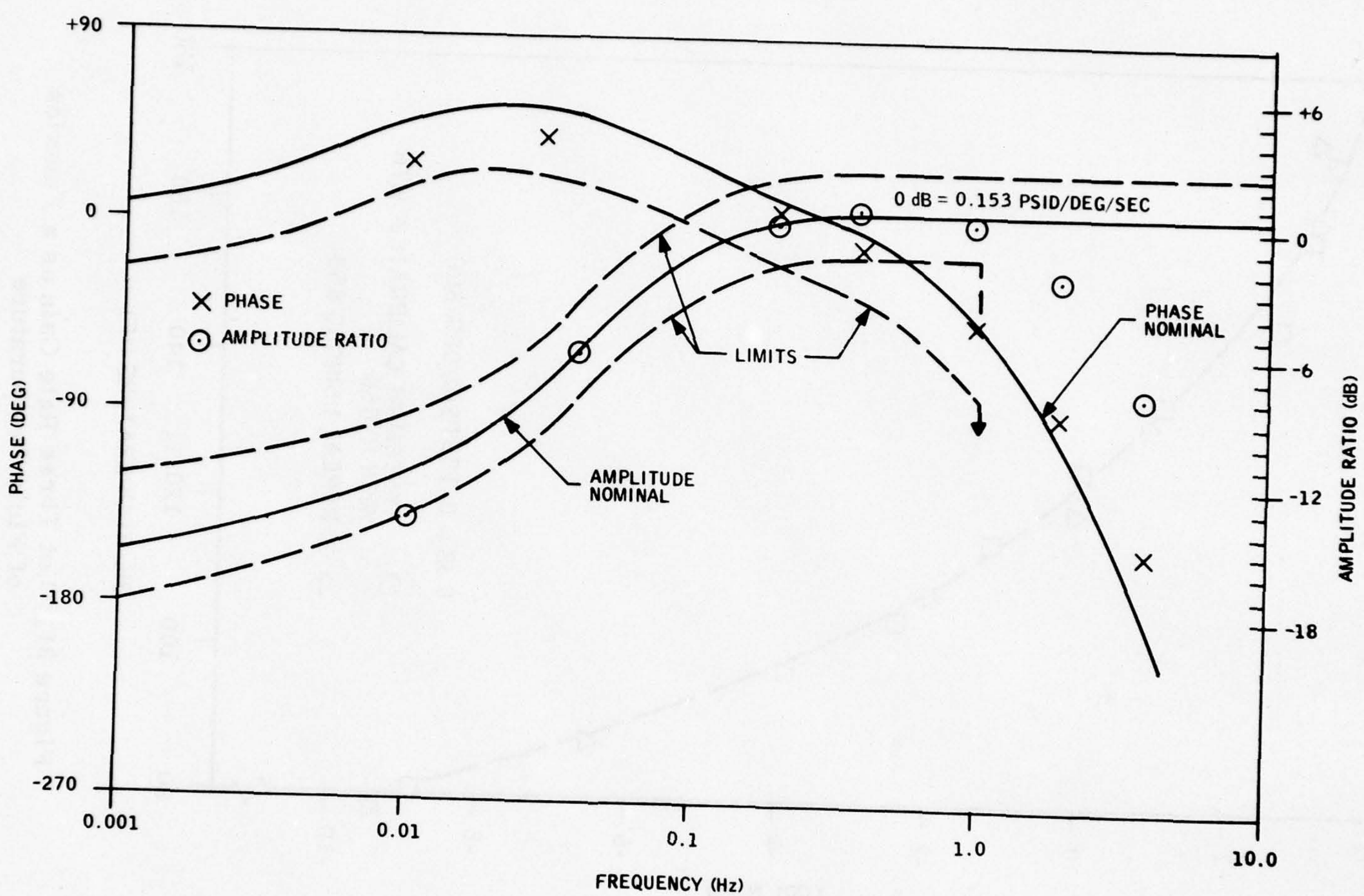


Figure 30. Lot Three Rate Response.

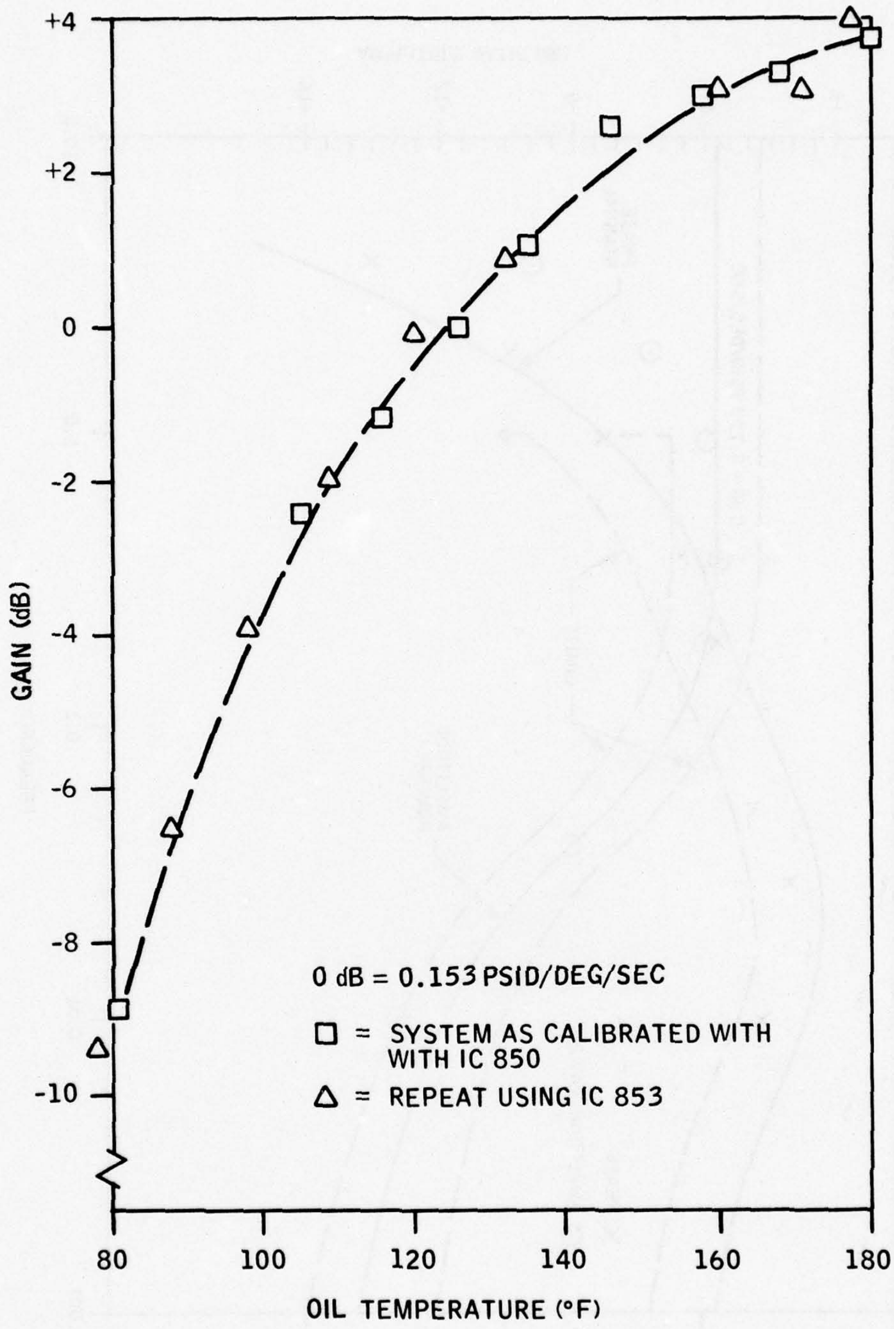


Figure 31. Lot Three Rate Gain as a Function of Fluid Temperature

major contributor. However, this reduced feedback is necessary to obtain the required system gain. Overall performance is good, and this system would be satisfactory for installation into the OH-58 helicopter yaw axis.

Minor changes were made in the system specifications due to component changes (and minor text errors). The original specification used as a guide was the text describing field test units under contract DAAJ02-73-C-0046. The final specification to be used for the Phase III production units is presented in Appendix E.

SECTION V
COMPONENT AND SYSTEM PERFORMANCE SUMMARY

PILOT INPUT DEVICE

Component testing proved to be an effective method of screening PID assemblies to uncover gross deviations in performance. The wide variations in PID gain, as shown in Table 12, is attributed to a poor surface finish on the sleeve bore. Gain on the first three units is expressed in terms of simulated lever arm travel rather than spool travel, and these numbers are not directly comparable with units four through nine. A substantial gain variation can be tolerated as the PID linkage can be shimmed to adjust overall PID gain.

TABLE 12. SUMMARY OF PID TESTING

		Sleeve Data			Spool Data	Performance	
	Controller	S/N	Slot Width (in.)	Slot Length (in.)	Diameter (in.)	Gain (psid/deg/in.)	Linearity (pct)
Lot 1	1	10	0.0040	0.4500	0.24940	1.53 (1)	(1)
	2	21	0.0040	0.4484	0.24925	1.14 (1)	(1)
	3 (2)	24	0.0040	0.4476	0.24940	1.50 (1)	(1)
Lot 4	4	16	0.0035	0.4428	0.24940	8.67	8.60
	5 (2)	9	0.0039	0.4426	0.24940	8.50	7.35
	6	35	0.0044	0.4424	0.24920	6.67	15.00
Lot 3	7 (2)	1	0.0039	0.4484	0.24940	9.38	23.30
	8	18	0.0039	0.4463	0.24940	7.56	11.20
	9	28	0.0039	0.4471	0.24940	9.69	9.30

(1) These units were tested on a setup that recorded simulated lever arm position, not spool position.

(2) Used in system tests.

VORTEX RATE SENSOR

Rate sensor dead-ended gain is an extremely consistent parameter among units in a single lot and is consistent between lots (Table 13). Dead-ended gain of the short-stem pickoff of Lot one appears to be about 15 percent less than that of the long-stem pickoffs in Lots two and three. Loads on Lot one were too small, and the flow-loaded gain was much higher than was experienced in system tests. Proper flow loading was provided for Lots two and three.

Null offset is the greatest variable in rate sensor performance; however, the degree of variation experienced in this program appears to be satisfactory.

TABLE 13. RATE SENSOR PERFORMANCE SUMMARY

Lot	Rate Sensor S/N	Dead-Ended Gain (psid/deg/sec)	Flow-Loaded Gain (psid/deg/sec)	Flow-Loaded Noise (psi-PP)	Offset Flow-Loaded (deg/sec)
	1	0.0080	0.0076 (1)	0.008	18.0
1	2 (2)	0.0076	0.0076 (1)	0.007	16.9
	3	0.0080	0.0074 (1)	0.001	10.7
	819 (2)	0.0094 (3)	0.0038 (3)	0.003	29.6 CW
2	820	0.0094 (3)	0.0033 (3)	0.006	70.0 CW
	821	0.0089 (3)	0.0036 (3)	0.003	32.0 CCW
	830	0.0092 (3)	0.0047 (3)	0.005	30.7 CCW
3	831	0.0096 (3)	0.0052 (3)	0.002	18.6 CW
	832 (2)	0.0088 (3)	0.0044 (3)	0.004	8.8 CW

(1) Excessive flow-loaded gain indicated.

(2) Used in system tests.

(3) These numbers are modified upward by about 10 percent from earlier reports as a result of later equipment calibration data.

INTEGRATED CIRCUITS

IC test results are summarized in Table 14. Variations in rate amplifier gain and through-rate gain are consistent with the circuit and test fixture modifications for each of the lots. The output amplifier cascade was one of the few areas of the IC that remained unchanged throughout all three lots.

SYSTEM

Components from each lot were assembled into a system and tested. Table 15 defines the configuration of the tested system for each lot.

System test results for each lot are summarized in Table 16. The required ratio of PID gain to rate gain could not be attained on Lot one due to excessive rate cascade gain. Eliminating one stage on the rate cascade in Lot two made it possible to attain the required gain ratio; however, overall gain was too low due to excessive feedback in the output cascade. Proper feedback resistors were designed for Lot three, and the required system gains were obtained. The Lot three configuration was selected for Phase III production without further modification.

TABLE 14. INTEGRATED CIRCUIT PERFORMANCE SUMMARY

Lot	Integrated Circuit (S/N)	Rate Sensor Amplifier Gain (psid/psid)	PID Amplifier Gain (psid/psid)	Through-Rate Gain (psid/deg/sec)	Output Cascade Gain - No Feedback (psid/psid)	Output Cascade Gain - Feedback (psid/psid)
1	805	15.5 (1)	2.9	18.6 (1)(2)	56	
	806	16.0 (1)	3.4	16.5 (1)(2)	53	
	807 (3)	9.0 (4)	4.0	24.0 (2)(4)	57	
2	818 (3)	1.8 (5)(6)	3.5	3.8 (2)(5)(6)	53	
	822	3.1 (5)	4.1	7.2 (2)(5)	54	
	823	3.2 (5)	3.7	7.3 (2)(5)	54	
3	850 (3)	4.3 (5)	3.3	11.8 (5)(7)	59	9.3
	851	3.6 (5)	3.5	11.8 (5)(7)	51	9.0
	853	4.0 (5)	3.4	11.5 (5)(7)	49	9.2

(1) These circuits have a two-stage rate cascade with a high-gain second stage.

(2) 0.016 inch diameter through-rate resistors used.

(3) These units were selected for later system tests.

(4) This circuit has a two-stage rate-cascade with a lower-gain second stage.

(5) Rate sensor cascade reduced to only one stage.

(6) Tested with R3 and R26 resistor blanks, which were too restrictive.

(7) 0.022 inch by 0.022 inch square electroformed through-rate resistors used.

TABLE 15. CONFIGURATION OF THE PHASE II SYSTEMS

Lot	Controller (S/N)	IC (S/N)	PID (S/N)	Rate Sensor (S/N)
1	3	807	24	2
2	5	818	9	819
3	7	850	1	832

TABLE 16. SUMMARY OF PHASE II SYSTEM TEST RESULTS

Parameter	120°F Requirement	Lot One Test Results	Lot Two Test Results	Lot Three Test Results
High-Pass Rate Gain	0.153 ± 0.019 psid/deg/sec	0.169 psid/deg/sec	0.092 psid/deg/sec	0.157 psid/deg/sec
Through-Rate Gain	0.033 ± 0.005 psid/deg/sec	0.03 psid/deg/sec	0.019 psid/deg/sec	0.03 psid/deg/sec
PID Gain	33.4 ± 4.2 psid/in.	17.0 psid/in.	18.5 psid/in.	33.0 psid/in.
Noise (120°F)	±0.2 psid	±0.2 psid	±0.02 psid	±0.05 psid
Noise (178°F)		±0.25 psid	±0.010 psid	±0.25 psid
Offset	±0.4 psid	-0.3 psid	-0.3 psid	-0.1 psid

SECTION VI
CONCLUSIONS

- The pilot production line, which was fabricated and optimized in this phase of the program, is capable of producing satisfactory hydrofluidic yaw-axis control systems.

- Modification of the electroforming process improved bonding and resulted in a more uniform plating thickness on integrated circuits.

- Resistors can be accurately electroformed onto the integrated circuit. Their sensitivity to temperature can be either emphasized or minimized in a predictable manner.

- Viscosity-sensitive resistors in bias and bypass circuits have good potential for temperature compensation. Optimization of these techniques was beyond the scope of this program.

- Configuration of the 20 production units in Phase III will be identical to the unit calibrated in Lot three of this phase.

APPENDIX A

SPECIFICATION FOR PEDAL INPUT DEVICE (PID)

SPECIFICATION NO. DS 25515-01

TYPE: ☐ SYSTEM ☐ DEVELOPMENT ☐ PRODUCT ☒ OTHER

TITLE: PEDAL INPUT DEVICE (PID)

SIGNATURES		DATE
PREPARED BY	W. M. [illegible]	7-14-76
APPROVED BY PROJECT ENGR.		

REVISIONS

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HS-256

MT/X

1.0 SCOPE

This specification defines the requirements for identification and acceptance of the pilot input device (PID) which is a component in the YG1158A01 Yaw Stability Augmentation System.

2.0 APPLICABLE DOCUMENTS

The following documents, drawings, and specification shall apply to the extent specified herein:

MIL-H-5606	Hydraulic Fluid, Petroleum Base, Aircraft Missile and Ordnance.
DS 24860-01	Yaw Axis Stability Augmentation System

3.0 *REQUIREMENTS*

3.1 Standard Test Conditions

Fluid	MIL-H-5606 hydraulic fluid
Fluid Temperature	$120^{o}F \pm 5^{o}F$
Ambient Temperature	$70^{o}F \pm 5^{o}F$
Back Pressure	50 ± 5 psi
Supply Pressure	10.0 ± 0.05 psi above back pressure

3.2 Test Configuration

The PID shall be tested in the configuration shown in Figure 1. Input displacement shall be measured in terms of spool motion.

3.3 Component Performance

3.3.1 Gain

The PID gain shall be 7.8 ± 1.2 psi/inch of spool as measured over $\pm$ 0.04 inches of input.

3.3.2 Range

The spool range shall be a minimum of $\pm$ 0.06 inches. Linear range shall be $\pm$ 0.04 inches.

3.3.3 Linearity

The PID linearity shall be within 20% over a ± 0.04 inch input, i.e., deviation of the output from the nominal gain curve shall not exceed ± .06 psi over the ± 0.04 inch linear range after eliminating the effects of data scatter due to noise and hysteresis.

4.0 QUALITY ASSURANCE

4.1 Assembly and Identification

The PID spool and sleeve will be assembled into a system housing and serialized.

4.2 Test Set-Up

The PID will be mounted on a test fixture capable of testing the PID in the configuration of paragraph 3.2 and tested under the conditions of paragraph 3.1.

4.3 Component Performance

With a x-y plotter, draw a curve of differential output pressure as a function of cable displacement. Use the curve to determine the compliance with the requirements of paragraphs 3.3.1, 3.3.2, and 3.3.3.

DS 25515-01

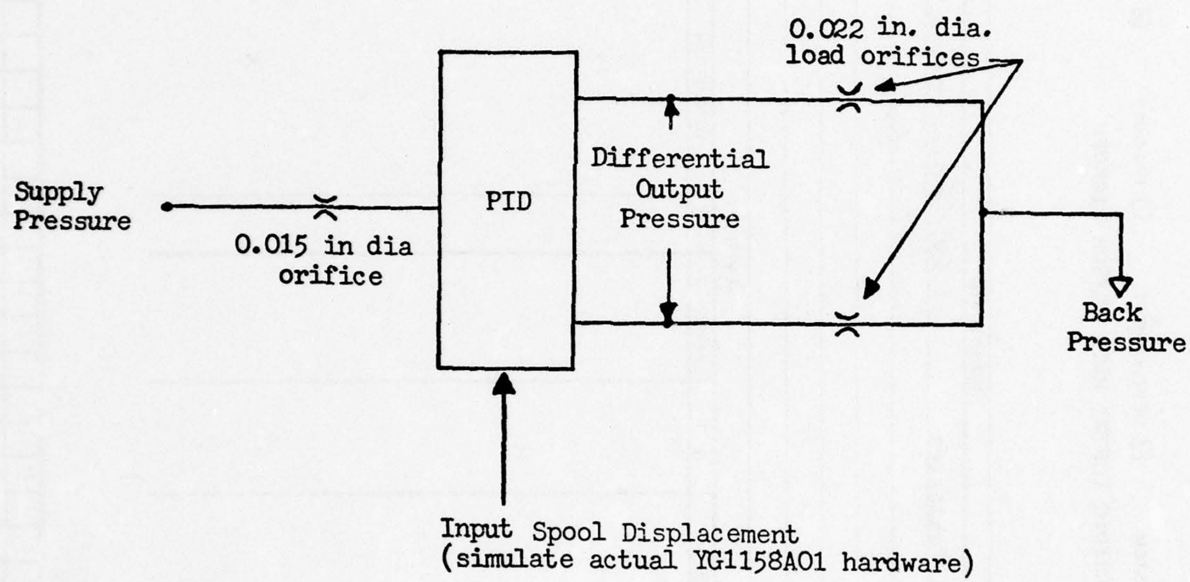

FIGURE 1

PID TEST CONFIGURATION

APPENDIX B

SPECIFICATION FOR HYDROFLUIDIC VORTEX RATE SENSOR PICKOFF

SPECIFICATION NO. DS 24949-01

TYPE: ☐ SYSTEM ☐ DEVELOPMENT ☐ PRODUCT ☒ OTHER

TITLE: **HYDROFLUIDIC VORTEX RATE SENSOR PICKOFF**

SIGNATURES		DATE
PREPARED BY	W. Posingies W. M. Posingies	6-30-76
APPROVED BY PROJECT ENGR.	[illegible]	6-30-76

REVISIONS

LTR	DESCRIPTION	DATE	APPROVAL	LTR	DESCRIPTION	DATE	APPROVAL

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PAGE 1 OF 3

DS 24949-01

MT/R

HS-256

1.0 SCOPE

This specification defines the performance of the hydrofluidic vortex rate sensor pickoff which is an electroformed component in the YG1158A01 Yaw Stability Augmentation System.

2.0 APPLICABLE DOCUMENTS

The following documents, drawings, and specifications shall apply to the extent specified herein.

MIL-H-5606	Hydraulic Fluid, Petroleum Base, Aircraft, Missile, and Ordnance
DS 24947-01	Yaw Axis Hydrofluidic Stability Augmentation System
10058162-101	Pickoff

3.0 REQUIREMENTS

3.1 Test Conditions

The rate sensor pickoff shall be tested under the following test conditions:

Fluid	MIL-H-5606 hydraulic oil
Fluid Temperature	$120^{\circ}F \pm 5^{\circ}F$
Ambient Temperature	$70^{\circ}F \pm 5^{\circ}F$
Supply Flow	1.90 ± 0.05 cis
Back Pressure	50 ± 5 psi

3.2 Test Configuration

The rate sensor pickoff shall be combined with the appropriate number of coupling rings and assembled into a test failure that simulates the YG1158A01 housing. The test fixture should have provisions for measuring input rate, supply pressure, supply flow, output pressure level, and differential output pressure. The rate sensor pickoff should be tested with the output deadened and loaded into 0.0225 inch dia. orifices. Size of the secondary sink orifice shall be 0.035 in. dia.

3.3 Pickoff Performance

3.3.1 Scale Factor: The deadened scale factor of the pickoff shall be .0094 ± 0.001 psi/deg/sec. With the sensor pickoff loaded into a pair of 0.0225 inch dia. orifices, the scale factor shall be 0.005 ± 0.001 psi/deg/sec.

3.3.2 Null: The deadened and flow-loaded null offsets shall not exceed an equivalent of ± 75 deg/sec.

3.3.3 Noise: The deadened and flow-loaded noise shall not exceed an equivalent of ± 1.0 deg/sec when measured through a double lag filter network with a time constant of 0.016 sec.

3.3.4 Range: The rate sensor pickoff shall have a minimum output range equivalent to ± 50 deg/sec input.

3.3.5 Linearity: The linearity shall be within ± 10% of the output range defined above.

4.0 QUALITY ASSURANCE

4.1 Assembly and Identification

The rate sensor pickoff shall be serialized and assembled with coupling rings.

4.2 Test Set-Up

The rate sensor pickoff with the coupling rings shall be mounted into the test fixture described in paragraph 3.2 and tested under the conditions of paragraph 3.1.

4.3 Component Performance

With a x-y plotter, draw a curve of differential output pressure as a function of rate input with the pickoff deadened and with the pickoff flow-loaded. Use the curves to determine compliance with the requirements of paragraphs 3.3.1, 3.3.2, 3.3.3, 3.3.4, and 3.3.5.

Also record the output pressure level, supply pressure, and return pressure for both conditions.

APPENDIX C

SPECIFICATION FOR HYDROFLUIDIC INTEGRATED AMPLIFIER MANIFOLD CIRCUIT

SPECIFICATION NO. DS 24950-01

TYPE: ☐ SYSTEM ☐ DEVELOPMENT ☐ PRODUCT ☒ OTHER

TITLE: HYDROFLUIDIC INTEGRATED AMPLIFIER MANIFOLD CIRCUIT

SIGNATURES		DATE
PREPARED BY	W. M. Posingie	7-14-76
APPROVED BY PROJECT ENGR.		

REVISIONS

LTR	DESCRIPTION	DATE	APPROVAL	LTR	DESCRIPTION	DATE	APPROVAL

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SPECIFICATION NO. DS 24950-01

1.0 SCOPE

This specification defines the performance for the Integrated Amplifier-Manifold Circuit. This electroformed unitized hydrofluidic circuit package is a component in the YG1158A01 yaw Stability Augmentation System.

2.0 APPLICABLE DOCUMENTS

The following documents and drawings and the applicable specifications referenced therein shall apply to the extent specified herein.

MIL-H-5606	Hydraulic fluidic, Petroleum Base, Aircraft, Missile and Ordnance
DS 24860-01	Yaw Axis Hydrofluidic Stability Augmentation System
C 13789AA01	Circuit Schematic
10050022	Manifold, Amplifier

3.0 REQUIREMENTS

3.1 General

The integrated amplifier-manifold circuit conforming to drawing 10050022 shall contain the following circuits.

3.1.1 Rate Sensor Circuit

Amplifier, resistors and manifolds comprising this circuit provide impedance matching and amplification of rate sensor output signals. One signal from this circuit is summed with the output signal from the pilot input cascade at the input to the high pass capacitors. The other signal from the rate sensor circuit is summed in the output cascade.

3.1.2 Pilot Input Circuit

Components of this circuit provide impedance matching and amplification of pilot input device signals. The signal from this circuit is summed with an output from the rate sensor amplifier at the input to the high pass capacitors.

3.1.3 Output Cascade

Components of this circuit provide impedance matching and amplification of signals from both the high pass capacitors and the rate sensor circuit. Output from the output cascade provides impedance matched commands to the 10047853 servoactuator.

3.1.4 Bias Network

Restrictor and manifolding combine to provide bias flows to the downstream side of the high pass. Electroformed restrictors, provide the proper flow division between the two capacitors.

3.1.5 Manifolding

Additional manifolding in the integrated circuit distributes supply flow to amplifiers and to the pilot input device. Manifolds provide communication between components. Manifolds also function as a return "ground" for amplifiers, networks and the rate sensor.

3.2 Environment

3.2.1 Temperature

The integrated circuit shall operate over the ambient temperature range from $0^{O}F$ to $180^{O}F$ when the operating fluid is in the range of $+40^{O}F$ to $180^{O}F$.

3.3 Power Supply

3.3.1 Nominal Supply

Input power to the integrated circuit will be hydraulic fluid per MIL-H-5606 at a nominal pressure of 63 psig with a return pressure of 50 psig. Integrated circuit supply flow will be 0.7 cis (not including pilot input device flow).

3.3.2 Proof Pressure

Integrated circuit proof pressure will be 900 psig (1.5 x system supply pressure)

3.4 Circuit Performance

All performance requirements in this section pertain to normal operating conditions. Normal operating conditions are defined as:

Ambient Temperature	$70^{O}F \pm 5^{O}F$
Hydraulic Fluid Temperature	$120^{O}F \pm 5^{O}F$
Hydraulic Fluid Pressure	63 psig nominal ahead of circuit
	50 psig return pressure
Hydraulic Fluid Flow	0.7 $\pm$ .01 cis. (with pilot input device passage blocked).

3.4.1 Rate Sensor Circuit

Requirements apply when signal levels and load impedances are as defined in Figure 1. Signal (Δ P2) into the PID amplifier shall be zero.

3.4.1.1 Null - Output offset (Δ P5) shall not exceed 0.5 PSID.

3.4.1.2 Range - Linear range shall be at least 1.0 psid at the output (Δ P5). Slope of the output vs. input shall not reverse over an input range of $\pm$ 0.5 psid.

3.4.1.3 Gain - Rate circuit gain shall be 3.4 $\pm$ 0.5.

3.4.1.4 Noise - Noise at the output shall not exceed 0.03 psid peak to peak when measured by a double lag filter network with a time constant of 0.016 seconds.

3.4.1.5 Linearity - Cascade linearity over the output range of $\pm$ 1.0 psid shall be within $\pm$ 15% (i.e. $\pm$0.15 psid). Linearity is defined as the maximum deviation from an extension of the linear portion of the gain curve, within the required output range after eliminating the effects of noise.

3.4.1.6 Level - Output level (P7-1) shall be 5 $\pm$ 1 psid.

3.4.2 Pilot Input Cascade

Requirements apply when signal levels and output impedance are as defined in Figure 1. This Figure also defines locations for input and output. See section 3.4.1 for definitions of noise and lineariy.

3.4.2.1 Null - Null offset at the output (Δ P5), shall not exceed 0.5 psid.

3.4.2.2 Range - Linear range at the output shall be at least $\pm$ 1.0 psid.

3.4.2.3 Gain - Cascade gain shall be 3.4 $\pm$ 0.5.

3.4.2.4 Noise - Peak to peak noise at the output shall not exceed 0.03 psid.

3.4.2.5 Linearity - Cascade linearity shall be within $\pm$ 15% of the design output range (i.e. $\pm$ 0.15 psid).

3.4.3 Output Cascade

Requirements apply when signal levels, input impedance and output impedance are as specified in Figure 1. Unless otherwise specified through rate resistors (R22 and R23) will be operating and feedback resistors (R10 and R11) will be blocked.

3.4.3.1 Null - Input required at Δ P6 in order to null output at Δ P10 shall not exceed 0.05 psid. With flow to input no. 3 "off" and feedback resistors (R10 and R11) operating the differential pressure at Δ P4 required to null Δ P10 shall not exceed 0.10 psi.

3.4.3.2 Range - Output cascade range shall be $\pm$ 2.5 psid or greater when driven by input number three (Δ P3). This output shall not decrease to less than $\pm$ 2 psid when the ΔP3 input is increased to $\pm$ 0.4 psid. With the output cascade at null (Δ P3 = 0) inputs to the rate sensor circuit (Δ P1) shall provide a linear range at the output of $\pm$ 1.0 psid or greater.

3.4.3.3 Gain - Gain from Δ P6 to Δ P10 shall be 54 $\pm$ 11. Gain from Δ P4 to Δ P10 without feedback shall be 11.8 $\pm$ 1.8. Gain from Δ P3 to Δ P10 without feedback shall be 19 $\pm$ 4 and with feedback shall be 9.2 $\pm$ 1.4.

3.4.3.4 Noise - Peak to peak noise at the output shall not exceed 0.4 psi peak to peak.

3.4.3.5 Linearity - Cascade linearity shall be within $\pm$ 15% of the design output range (i.e. $\pm$ 0.15 psid for Δ P4 inputs over a $\pm$ 1.0 psid range and $\pm$ 0.30 psid for Δ P3 inputs over a $\pm$ 2.0 psid range).

3.4.3.6 Pressure level - With R22 and R23 operating and with the feedback operating the pressure level at P7-2 shall be 5 $\pm$ 1 psid above circuit return pressure.

3.5 Product Configuration

3.5.1 Drawing Number 10050022 is the assembly drawing for the integrated amplifier circuit.

4.0 QUALITY ASSURANCE

Every unit manufactured will be serialized, tested and data will be documented for future statistical analysis in accordance with the requirements set forth in this section.

All performance data shall be obtained at normal operating conditions which are defined as:

Ambient Temperature	$70^oF \pm 5^oF$
Hydraulic Fluid Temperature	$120^oF \pm 5^oF$

Test facility matched resistors shall be reversed periodically to demonstrate degree of matching.

4.1 Power Supply

4.1.1 Nominal Supply

Hydraulic fluid supply must conform to MIL-H-5606.

4.1.2 System Flow

With the circuit connected to the configuration defined in Figure 1 the supply flow shall be adjusted to 0.70 $\pm$ .01 cis. Record supply pressure level and maintain this difference between supply and return throughout quality assurance testing. Repeat total system input flow measurement after each major circuit change and record but do not change supply pressure.

4.2 Rate Sensor Cascade

Set up the rate sensor cascade with resistors and pressure levels as defined in Figure 1. Differential pressure at ΔP2 must be zero for these tests. Through rate resistors must be operating to obtain required levels.

Figure 2 outlines the method for establishing null and range characteristics of the rate sensor amplifier. Data are to be recorded on a form similar to that shown on Figure 3.

4.2.1 Null

Referring to Figure 2, establish the mid-point of the gain curve. Distance A is the null offset of the subject amplifier relative to its input. Record offset C which is the same offset related to the amplifier output. (Note: B is the offset of the PID amplifier in the example shown.) Compare C with the requirements of Paragraph 3.4.1.1.

4.2.2 Range

Record dimension h (See Figure 2) compare to the requirements of Paragraph 3.4.1.2.

4.2.3 Gain

Establish the slope of the ΔP5 vs. ΔP4 curve, record and compare to requirements of Paragraph 3.4.1.3.

4.2.4 Noise

Record peak to peak noise level at the ΔP5 location. Compare to Paragraph 3.4.1.4.

4.2.5 Linearity

Over the range of $\pm$ 1 psid about the amplifier point of symmetry measure the maximum deviation from the nominal gain line. After subtracting the effects of noise, record this deviation and compare to the requirements of Paragraph 3.4.1.5.

4.2.6 Level

Record level 7-1. Compare to requirements of Paragraph 3.4.1.6.

4.3 Pilot Input Cascade

The pilot input cascade (sometimes referred to as the PID amp) is summed with the rate sensor cascade. The method used to obtain null and range is shown on Figure 2. Data is to be obtained from the ΔP5 vs. ΔP2 gain curve where ΔP4 is maintained at zero ΔP.

4.3.1 Null

Record offset C defined in Figure B. Compare to requirements of Paragraph 3.4.2.1.

4.3.2 Range

Record dimension H (Figure 2) and compare to Paragraph 3.4.2.2.

4.3.3 Gain

Establish slope of the ΔP5 vs. ΔP2 curve, record and compare to the requirements of Paragraph 3.4.2.3.

4.3.4 Linearity

Measure linearity over the range of $\pm$1 psid and compare to the requirements of 3.4.2.5.

4.4 Output Cascade

Set-up the output cascade with resistors and pressure levels in accordance with Figure 1. Record required data on a form similar to Figure 3.

4.4.1 Null

Measure nulls in accordance with the requirements of Paragraph 3.4.3.1 and record.

4.4.2 Range

Obtain range data from amplifier gain curves, compare to the requirements of Paragraph 3.4.3.2 and record.

4.4.3 Gain

Obtain the four gain curves described in Paragraph 3.4.3.3, calculate circuit gain under each condition and record.

4.4.4 Noise

Record noise at the output of the cascade and compare to requirements of 3.4.3.4.

4.4.5 Linearity

Calculate linearity for the conditions outlined in 3.4.3.5 and record.

4.4.6 Pressure Level

Record level at P7-2 and compare to requirements of Paragraph 3.4.3.6.

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PRODUCTION SUITABILITY OF AN ELECTROFORM CONDUCTIVE WAX PROCESS--ETC(U)
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UNCLASSIFIED GAPD-2760-47021 USAAMRDL-TR-76-42 NL

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INTEGRATED CIRCUIT TEST DATA

I.C. Number ____________ Lot Number ____________ Date ____________

Fluid Temp ____________ Ckt. ΔP ____________ Flow ____________

Circuit	Parameter	Recorded Value	Requirement	Paragraph
Rate Sensor	Null (Δ P5)		± 0.5 PSID	3.4.1.1
	Range		± 1 PSID	3.4.1.2
	Reversal		± 0.5 PSID in	3.4.1.2
	Gain		3.9 ± 0.5	3.4.1.3
	Noise		0.03 Max	3.4.1.4
	Linearity		± 0.15 PSID	3.4.1.5
	Level (7-1)		5 ± 1 PSID	3.4.1.6
PID Amp	Null (Δ P5)		± 0.5 PSID	3.4.2.1
	Range		± 1 PSID	3.4.2.2
	Gain		3.6 ± 0.5	3.4.2.3
	Linearity		± .15 PSID	3.4.2.5
Output Cascade	Null (Δ P6)		0.06 PSI Max	3.4.3.1
	Null (Δ P4)		0.10 PSI Max	3.4.3.1
	Range (Δ P3 Input)		± 2.5 PSID	3.4.3.2
	Range (Δ P4 Input)		± 1.0 PSID	3.4.3.2
	Gain Δ P6/ Δ P10		54 ± 11	3.4.3.3
	Gain Δ P4/ Δ P10		11 ± 1.8	3.4.3.3
	Gain Δ P3/ Δ P10 (No FB)		19 ± 4	3.4.3.3
	Gain Δ P3/ Δ P10 (FB)		9.2 ± 1.4	3.4.3.3
	Noise		0.4 PSI Max	3.4.3.4
	Linearity Δ P3		± .3 PSI Max	3.4.3.5
	Linearity Δ P4		± .15 PSI Max	3.4.3.5
	Pressure Level P7-2		5 ± 1 PSID	3.4.3.6

FIGURE 3

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INTEGRATED CIRCUIT TEST SCHEMATIC

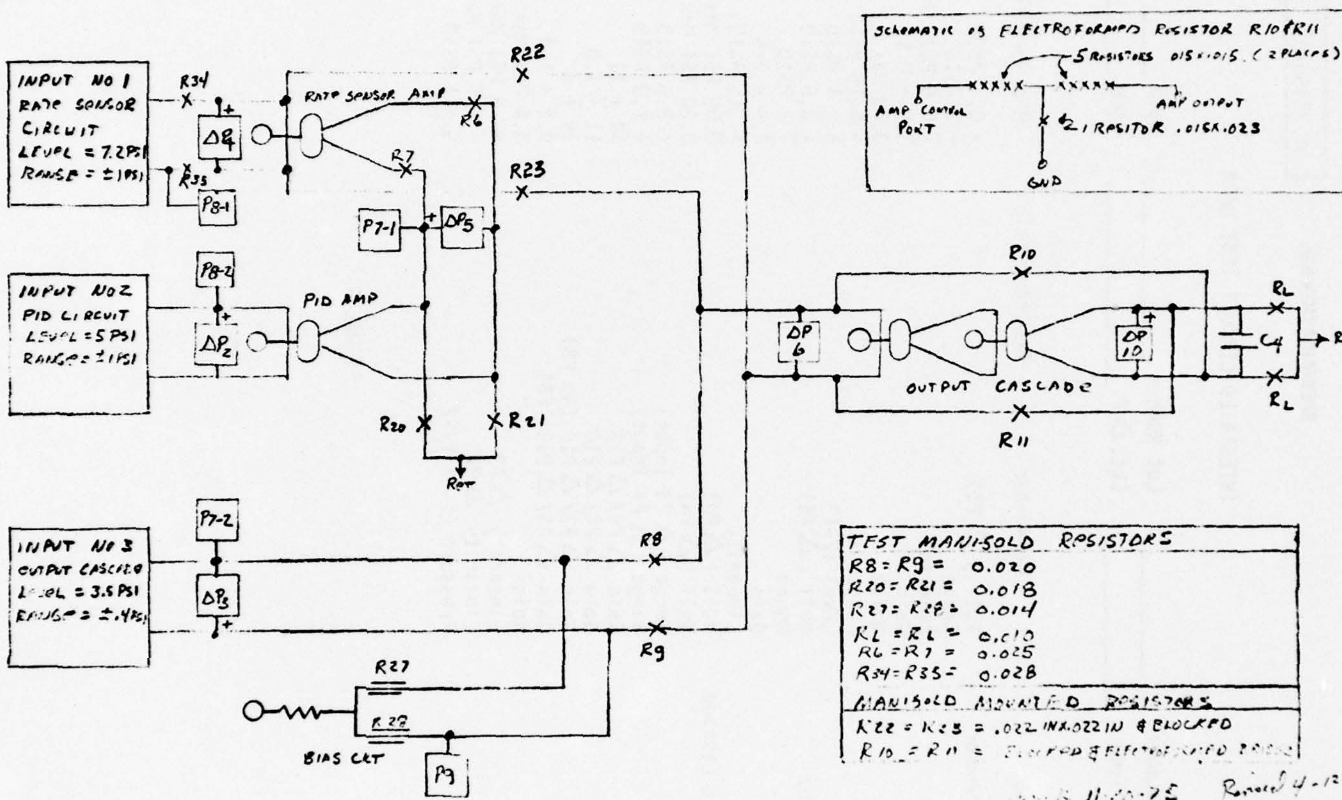

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FIG 1.

NULL MEASUREMENTS WHEN
TWO AMPLISIERS SUM TOGATHER

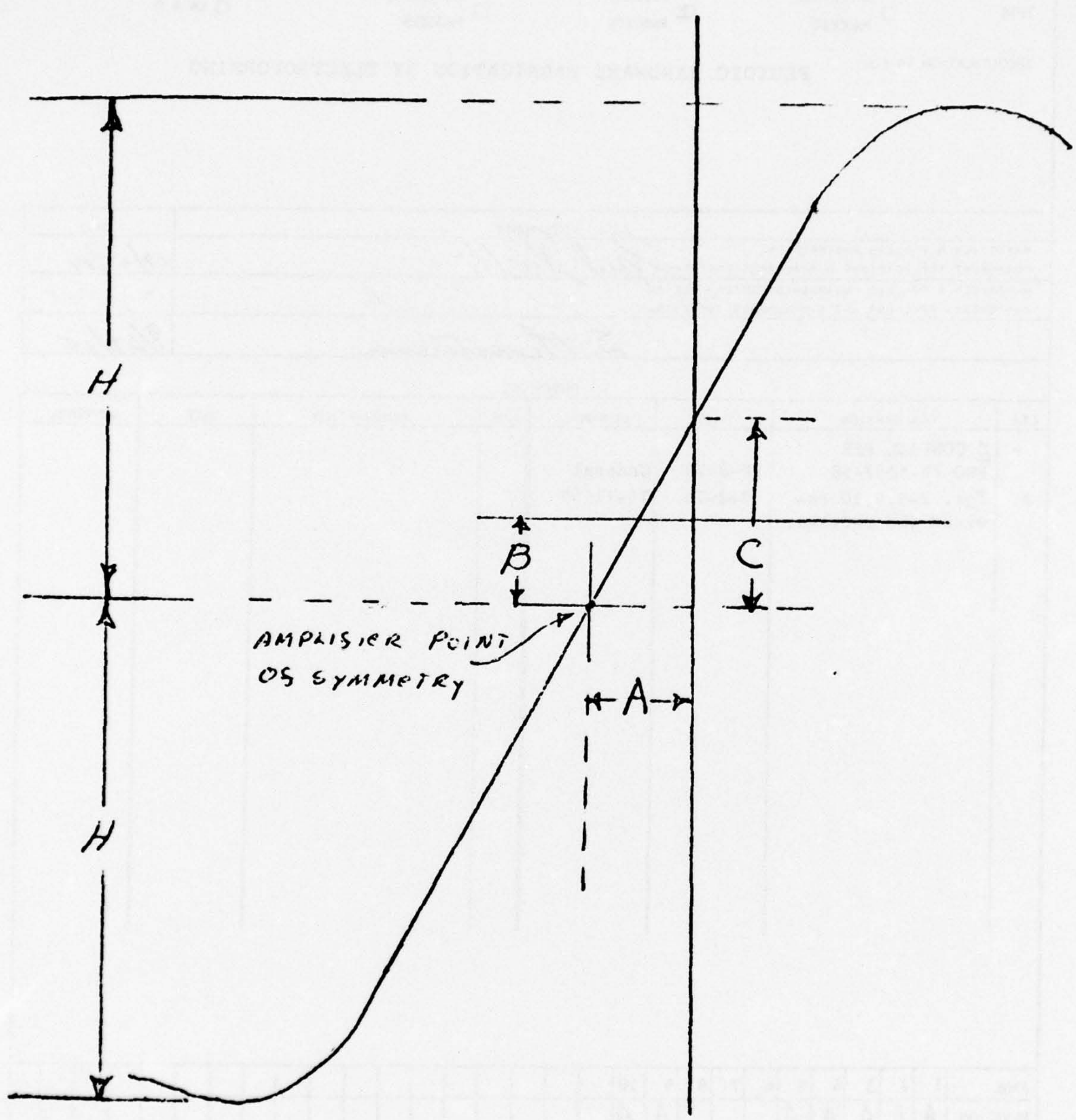

FIG 2

APPENDIX D
SPECIFICATION FOR FLUIDIC HARDWARE FABRICATION BY ELECTROFORMING

PROCESS SPECIFICATION NO. PC13502-01

THIS ☐ MATERIALS PROCESS ☒ ASSEMBLY PROCESS ☐ MEASUREMENTS PROCESS ☐ CA & S

SPECIFICATION IS FOR: FLUIDIC HARDWARE FABRICATION BY ELECTROFORMING

SIGNATURES		DATE
MATERIALS & PROCESS ENGINEER OR COMPONENT APPLICATIONS & STANDARDS ENGINEER	Paul Porelli	09/07/74
MATERIALS & PROCESS ENGINEERING SUPERVISOR OR COMPONENTS APPLICATIONS & STANDARDS SUPERVISOR	[illegible]	[illegible]
	S. Thorsteinsson	9/29/75

REVISIONS

LTR	DESCRIPTION	DATE	APPROVAL	LTR	DESCRIPTION	DATE	APPROVAL
-	C CONTROL PER ERO 75-5047-58	10-8-75	General				
A	Pgs. 2-5,9,10 revised and redrawn.	7-2-76	76-11669				

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PROCESS SPECIFICATION NO. PC 13502-01

FLUIDIC HARDWARE FABRICATION BY ELECTROFORMING

1 SCOPE

1.1 This specification covers a developmental process for fabrication of fluidic hardware by electroforming. This process is limited to 303 corrosion resistant VRS pickoff baseplates, 301 or 302/304 corrosion resistant steel baseplates, 45 RC steel VRS pickoff molds, and brass molds.

2 APPLICABLE DOCUMENTS

There are no applicable documents.

3 REQUIREMENTS

3.1 Materials - The materials shall be as described in Table I for the use given therein.

TABLE I - PROCESS MATERIALS

Material	Description	Use
Wax	Glyco S-932 (Glyco Chem. Co.)	Expendable mandrel
Wax	Paraffin	Expendable mandrel
Graphite	Dixon 620 (Dixon Carbon Co.)	Expendable mandrel
Carbon	Acetylene Black (Union Carbide)	Expendable mandrel
Sulfuric Acid	H_2SO_4 AR Grade 10% Solution	Baseplate preclean
Nickel plating Solution	Barret Type SN sulfamate nickel plating solution	Nickel electroforming

TABLE I - PROCESS MATERIALS (Continued)

Material	Description	Use
Solvent	Trichloroethylene, Tech Grade	Degreasing and mandrel removal
Anodes	Nickel rolled, sulfur depolarized	Source of nickel
Anode bags	Dynel or polypropylene	Reduce anode particulate contamination for sulfamate nickel
Water	Deionized, 10ppm total solids, max, 1 megohm resistance, min.	Solution makeup, replenishment, and rinses
Compressed air	Filtered, oil free	Drying and mandrel removal
Nickel strike	1) Nickel Chloride ($NiCl_2$ $6H_2O$), AR Grade 8 oz/gal nickel metal content 2) Hydrochloric acid (HCl), 36.8% AR Grade, 1 pint/gal	Nickel strike
Blasting abrasive	Per layout	Surface perparation
Masking tape	3M No. 8403	Masking

3.2 Equipment - The equipment shall be as described in Table II, with size appropriate for the expected work.

TABLE II - EQUIPMENT

Item	Description	Use
Tank	Suitable for nickel electroforming	Nickel electroforming
Tank	Suitable for water rinses	Rinsing as specified

TABLE II - EQUIPMENT (Continued)

Item	Description	Use
Tank	Suitable for H_2SO_4 cleaning	Baseplate preclean
Tank	Suitable for nickel strike	Baseplate activation
Exhaust system	Suitable for plating shop	Operator and facility safety
Filter system	Sethco (or equivalent)	Purifying nickel sulfamate solution
Filter elements	Sethco #10 filter elements, 5 micron	Replacement filter elements
Pumps, two	March Mfg. or equivalent suitable for electrcforming	Sulfamate solution agitation
Pumps, two	March Mfg. or equivalent	Nickel strike solution agitation and H_2SO_4 solution agitation
Heaters	Quartz immersion heater for sulfamate nickel solution	Provide process heat
DC Power source	Providing direct current as required	Current for H_2SO_4 tank, nickel strike tank, and electroforming
Injection molder	Of suitable capacity, equipped for vertical clamping of baseplate and mold	Inject conductive wax into molds

TABLE II - EQUIPMENT (Continued)

Item	Description	Use
Ultrasonic cleaner	Mettler Electronics	Degreasing baseplate
High pressure pump	With *Trichloroethylene*	
Plating manifolds	Of suitable spray *pattern for parts* to be electroformed	For nickel strike, H_2SO_4 tank, and electroforming tank
Vacuum pump	Welch duo seal (or equivalent)	Remove air from mold before wax injection
Plating rack	As suitable	Holding parts during processing
Gram balance	Ohaus Scale Corp. accurate to 1/10th gram	Weighing ingredients of conductive wax
Masks, plugs	Polyethylene or other	Masking during plating
AC Power source	Providing alternate current as required	Current for heaters, pumps, molder, and other equipment.

3.3 Engineering requirements

3.3.1 Equipment set-up - The items listed in Table II shall be set up and utilized as in standard plating shop use. This applies also to safety equipment.

3.3.2 Solution make-up and maintenance - The sulfamate nickel plating solution and the nickel strike solution shall be used in the standard composition.

3.3.3 Operator qualification - Only operators who are considered capable by the responsible production engineer shall be qualified to perform the processing covered by this specification. Assistance in establishing pertinent criteria for operator qualification shall be available from the PLZT/Hydrofluidics Laboratory.

3.4 Operator procedure - The operator(s) shall perform the activities described herein in natural sequence.

3.4.1 Facility check-up - Prior to production operation daily (or at the beginning of the first of three shifts when continuous) the operator shall check that the items described in Table III meet the requirements listed therein.

TABLE III - PLATING CONDITIONS

Item No.	Item	Condition
1	Power	DC and AC power supply available with appropriate controls
2	Analysis of solutions	Samples taken and analyzed after every 24 hours of operation but at least once in each 3 week period. Analyses shall be made on schedule (within 24 hours of sample taking) and additions made as required. No solution shall be used if not within limits
3	Materials	Readily available
4	Exhaust System	In good working condition
5	Filter system	Operative, with filters replaced as required.

TABLE III - PLATING CONDITIONS (Continued)

Item No.	Item	Condition
6	Pumps and heaters	In satisfactory working condition, providing agitation and heat as required.
7	Injection molder	Clean, ready for use, controls satisfactory
8	Balance	Accurate - as checked with standard weight
9	Ultrasonic cleaner and degreaser	Clean, operative, charged with fresh trichloroethylene
10	Vacuum pump	Operative, controls calibrated
11	Compressed air source	Filters and pressure satisfactory
12	Deionized water	Source satisfactory
13	Abrasive blaster	Charged with appropriate abrasive

3.4.2 Assembly of baseplate, mold, and wax - The preparation of the parts and material for electroforming shall begin as follows.

3.4.2.1 Preparation of conductive wax -

a) Break up the waxes listed in Table I and mix thoroughly with the graphite and acetylene black in the proportions of 22.5 percent of each wax, 5.5 percent of acetylene black, and 49.5 percent graphite.

b) Melt these together at 150 - 250°F in a shallow pan, stir thoroughly, and allow to harden. Break or cut the solidified material into pieces of a size appropriate for feeding the injection molder.

3.4.2.2 Preparation of baseplate and mold assembly -

a) Abrasive blast the baseplate as indicated on the applicable drawing, using the abrasive specified on the layout for the part. Blast until no more surface changes become visible, using a suitable pressure. Wash the abrasive grit from the baseplate with tap water.

b) Using trichloroethylene, clean the baseplate in the ultrasonic cleaner.

c) Check the pertinent mold to make sure the mating surface is free from leak sources. Assemble it to the baseplate and clamp together in the injection molder.

d) Evacuate the mold with the vacuum pump.

3.4.2.3 Injection of wax and preparation of pre-electroform assembly -

a) Charge the injection molder with the wax, setting it for 160°F and at a pressure setting and mold temperature as specified on layout.

b) With the wax at the desired temperature and pressure, and the mold under vacuum, fill the mold cavity.

c) Release the vacuum and allow the air pressure to return to atmospheric level.

d) Remove the assembly from the mold and then remove the mold carefully from the baseplate.

e) Inspect the baseplate for good wax adhesion. Inspect the wax for freedom from cracks or other irregularities.

f) If the wax and baseplate are satisfactory, mask the baseplate as shown on the applicable drawing, using the masking tape and/or masks and plugs. Then assemble the pre-electroform to the plating rack.

3.4.3 Electroforming procedures - Activation, nickel strike, and electroforming shall be as follows:

a) Immerse the racked parts in the tank charged with 10 percent sulfuric acid. Connect the parts to the positive lead of the power supply at a current level which causes bubbling to take place and then is reduced just until the bubbling stops. Make sure the parts are held in agitated solution. Remove after 15 minutes.

b) Immerse racked baseplates in the nickel strike tank (with the unbagged nickel anodes), connect the parts to the negative lead of the power supply (current per layout) and apply power for 5 minutes ± 30 seconds.

c) Performing the work as rapidly as possible, rinse the racked parts in deionized water, immerse in the Barret sulfamate nickel electroforming solution tank (with nickel anodes in anode bags), connect to the negative lead of the power supply at the current given on the layout, and plate for as long as required by the layout.

Note: Before immersing VRS pickoffs in electroforming bath, flush each stem for 2-3 seconds with electroforming solution to remove any trapped air from the slot.

d) Remove the racked parts from the electroforming solution tank, rinse with deionized water, and then remove the parts from the rack.

e) Blow the parts dry with clean air and immerse them in hot trichloroethylene (150°F to boiling) so that the wax melts. Assist the removal of the wax by flushing with a stream of the hot solvent flowing through the channels. Persist in the wax removal procedures until the passages are completely clean.

3.4.3 Electroforming procedures - (Continued)

f) Visually inspect each part for freedom from pinholes and the presence of the desired matte silver surface appearance of the nickel.

g) Identify each part so that it can be traced back to the documents applicable to its development or production.

3.5 Workmanship - The workmanship shall be such that the parts are neatly and uniformly made and are free from defects which might affect their intended use.

4 QUALITY ASSURANCE PROVISIONS

4.1 Acceptance - Acceptance shall be based upon satisfactory process control and workmanship.

4.2 Inspection - When examinations are necessary for assurance that the parts meet the requirements, the methods shall be as follows.

4.2.1 Process control - Verification that the parts were made with the materials, equipment, baseplates and molds, temperatures, times and electrical requirements in accordance with the methods specified herein shall constitute satisfactory process control.

4.2.2 Workmanship - The workmanship shall be checked by visual inspection aided by equipment as necessary to determine that the parts meet the requirements of the drawing and are functional.

5 PREPARATION FOR DELIVERY

This section is not applicable to this specification.

6. NOTES

6.1 Safety - The materials and processes referred to herein may present hazards. The responsibility for safety lies with the using department. Technical assistance may be obtained from the Material and Process Engineering department.

APPENDIX E

SPECIFICATION FOR YAW AXIS HYDROFLUIDIC STABILITY AUGMENTATION SYSTEM

DETAIL SPECIFICATION PART *I* OF *II* | **DS** 24947-01

PART I, PERFORMANCE/DESIGN AND QUALIFICATION REQUIREMENTS

THIS DETAIL SPECIFICATION IS FOR: Yaw Axis Hydrofluidic Stability Augmentation System

SIGNATURES			DATE
PREPARED BY	W. M. Posingies	W M Posingies	6-23-76
APPROVED BY PROJECT ENGR.	R. A. Evans	R A Evans	6-23-76

REVISIONS

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DETAIL SPECIFICATION NO. DS 24947-01

1.0 SCOPE

This specification defines the performance requirements for the YG1158A01 yaw Stability Augmentation System. The system is a hydrofluidic control package which mounts on top of the boost and SAS actuator of the OH-58A helicopter. The system is added tothe aircraft to improve the handling qualities in the yaw axis.

2.0 APPLICABLE DOCUMENTS

The following documents and drawings and the applicable specifications references therein shall apply to the extent specified herein.

2.1 MIL-H-5606, Hydraulic Fluid, Petroleum Base, Aircraft, Missile and Ordinance.

C13789AA01, Circuit Schematic

3.0 REQUIREMENTS

3.1 General

The system shall consist of the following functional units.

3.1.1 Rate Sensor - A vortex rate sensor provides a differential pressure signal that is proportional to the aircraft angular rate in the yaw axis.

3.1.2 Amplifier - Accept and amplify differential pressure signals.

3.1.3 Shaping Networks - A combination of resistors and capacitors (bellows).

3.1.4 Pilot Input Device - Provides an output which is a function of pedal displacement. This will reduce the tendency of the control system to "fight" the pilot in the yaw axis.

3.1.5 Flow Control Valve - Maintain a constant flow to the system when provided a differential pressure of over 100 PSID.

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3.2 Environment

3.2.1 Temperature - The system shall operate over the ambient temperature range from 0° to +120°F when the operating fluid is in the range of +40°F to ±180°F.

3.3 Power Supplies

3.3.1 Input power to the system shall be hydraulic fluid per MIL-H-5606 at a pressure of 600 PSIG (nom which is obtained from the aircraft hydraulic power system). The system shall not require more than 2.7 cis.

3.4 System Performance

All performance requirements in this section pertain to normal operating conditions. Normal operating conditions are defined as:

Ambient Temperature - 70° ± 5°F
Hydraulic Fluid Temperature - 120°F ± 5°F
Hydraulic Fluid Pressure - 500 to 600 PSIG ahead of the flow regulator; a minimum of 50 PSIG return pressure

3.4.1 System requirements are summarized in Figure 1.

3.4.2 Range - The system shall have a range of at least ±30 degrees per second ahead of the high pass and ±100% actuator stroke downstream of the high pass.

3.4.3 Linearity - The system linearity shall be within ±10% of range. Linearity is defined as the width of the band enclosing all the test points.

3.4.4 Noise - Peak-to-peak noise shall not exceed ±.2 psid when measured thru a double lag filter network with a time constant of .016 seconds.

3.4.5 Accuracy - The system shall maintain gain and time constants within tolerances shown in Figures 2 and 3 for the high pass and pilot input loops.

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3.4.6 Phasing - CCW rotation of the system shall cause the pressure at port Pc1 to be greater than Pc2 (YG1158A drawing). CW rotation of the PID arm looking from the top shall cause the pressure at port Pc1 to be greater than Pc2 (right pedal).

3.4.7 Null - the null offset at zero input turning rate shall be no greater than ±.4 psid.

3.5 Component Performance

Performance shall be determined at room temperature ambient with fluid at 120° ± 5°F, unless otherwise specified.

The vortex rate sensor shall meet the following performance requirements when the system is supplied with 2.7 cis.

Scale Factor	≈0.008 PSID/degree/sec, dead-ended
Range	±30°/sec min.
Linearity	±5% of full scale
Time Delay	0.060 sec or less
Noise	±0.5 deg/sec max.

Calibrate Button - A sensor calibrate button shall be utilized with the capability of inserting a signal equivalent to a step rate of about 5 degrees per second.

3.5.2 Amplifier - Amplifiers shall meet the following performance requirements when supplied with a pressure of 6.5 PSID.

Input Impedance for VRS load amplifier -- 180 ohms minimum
Output Impedance for output amplifier -- 100 ohms maximum
Gain and Load - Requirements for each application are described in Figure 1.

3.6 Product Configuration

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3.6.1 Drawing Number YG1158A is the assembly and installation drawing.

4.0 QUALITY ASSURANCE

Conformance of the hardware to program objectives shall be evaluated with the following flightworthy test. Performance tests will be conducted before and after vibration tests. Vibration testing shall be conducted on the first unit only.

4.1 Vibration

4.1.1 A 15 minute vibration scan, with the system operating and output null monitored, will be conducted in each of the three axes at 2 g's from 50 to 500 cps. The testing shall be conducted with the hydraulic supply and connection simulating the actual aircraft installation as near as practicable.

4.2 Performance Tests

4.2.1 Conformance to dynamic range requirements of Paragraph 3.4.2 shall be determined by imposing rates of ±30°/sec and measuring final system output.

4.2.2 Gain and response requirements shall be determined by measuring system output at 0.01, 0.04, 0.2, 0.4, 1.0, 4.0 and 10 cps. Amplitudes of ±2, ±5*, ±10 and ±15°/sec shall be used. Response shall be measured with fluid temperatures of 70, 90, 120* and 180°F. Results shall meet the requirements of Para. 3.4. Temperature and amplitude marked with * are the requirements for acceptance testing.

4.2.3 Gain and response of the pilot input device shall be determined by measuring system output at 0.01, 0.04, 0.1, 0.4 and 1 cps. Amplitude of ±.04 inches of cable shall be used. Response shall be measured at the same temperatures as in para. 4.2.2. Results shall meet the requirements of para. 3.4.

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4.3 Verification

4.3.1 The systems shall be inspected for quality of workmanship and conformance to installation drawing.

4.3.2 Determine that the system contains the features described in Para. 3.6.1.

4.3.3 Establish that the power required does not exceed the amount specified in 3.3.1.

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COMPONENTS

G_{VRS}	$= 0.008\ e^{-0.06s}$ D.E.	psi/deg/sec	Typical Component Gains
G_{PID}	$= 0.6$	psi/in. of cable	
G_{amp1}	$= 1.0$	psi/psi	
G_{amp2}	$= 3.7$	psi/psi	
$G_{amp3\&4}$	$= 19$	psi/psi	
G_{cable}	$= 0.276$	in cable/in linkage	
$G_{linkage}$	$= 0.527$	in linkage/in pedal	

SYSTEM LOOP GAINS

Rate Loop:

$$G_R = \left[0.135\left(e^{-.06s}\right)\left(\frac{2.5S}{2.5S+1}\right) + 0.027\left(e^{-.06s}\right)\right] \text{ psi/deg/sec}$$

Pid Loop:

$$G_{PID} = 45.2\ \frac{1}{S+1}\ \frac{2.5s}{2.5s+1} \text{ psi/in cable}$$

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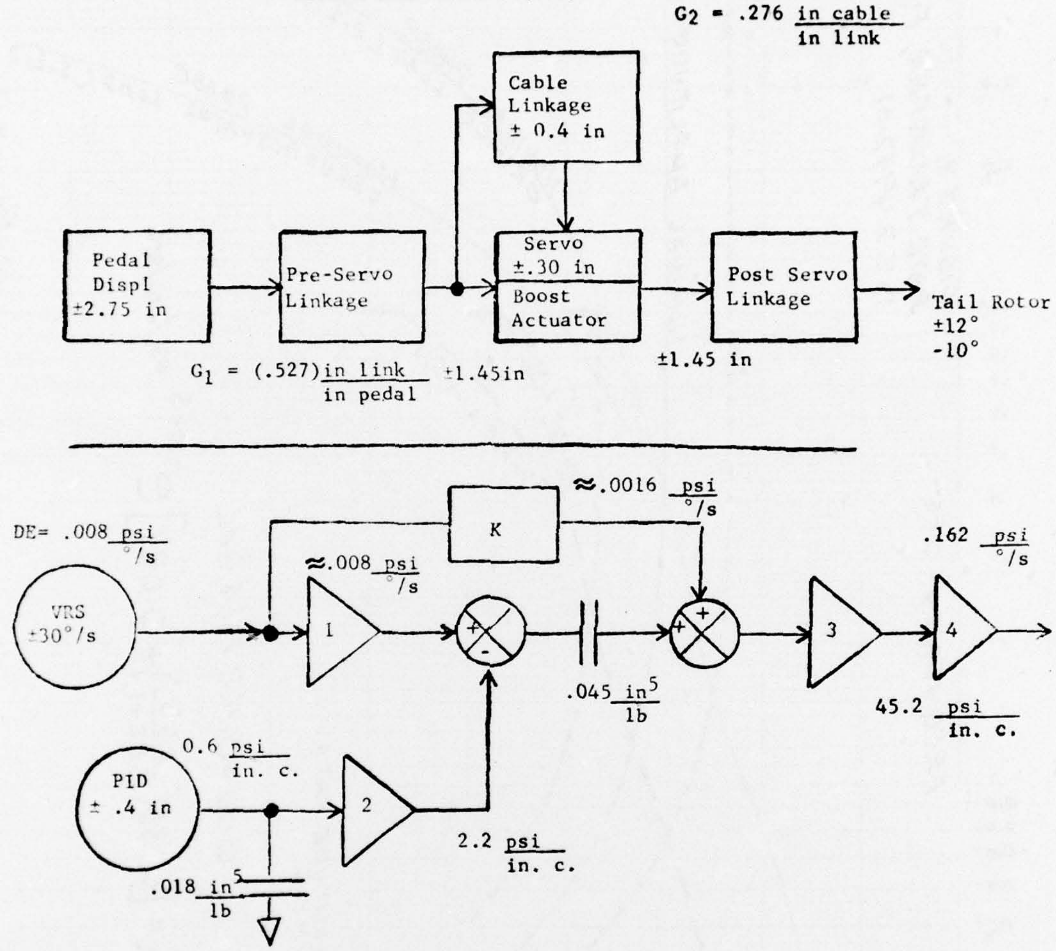
FIGURE 1
SYSTEM PERFORMANCE (YAW)



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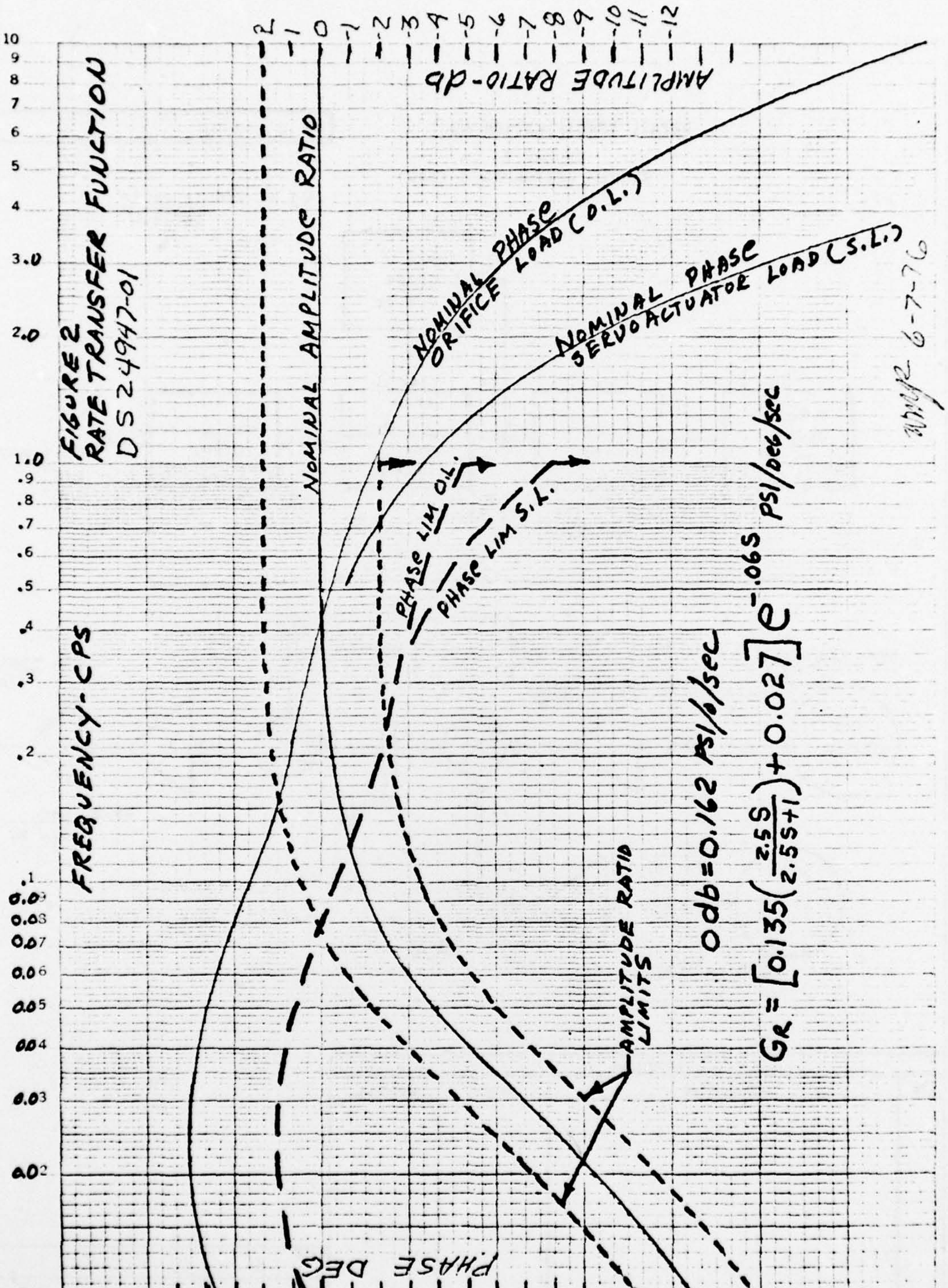
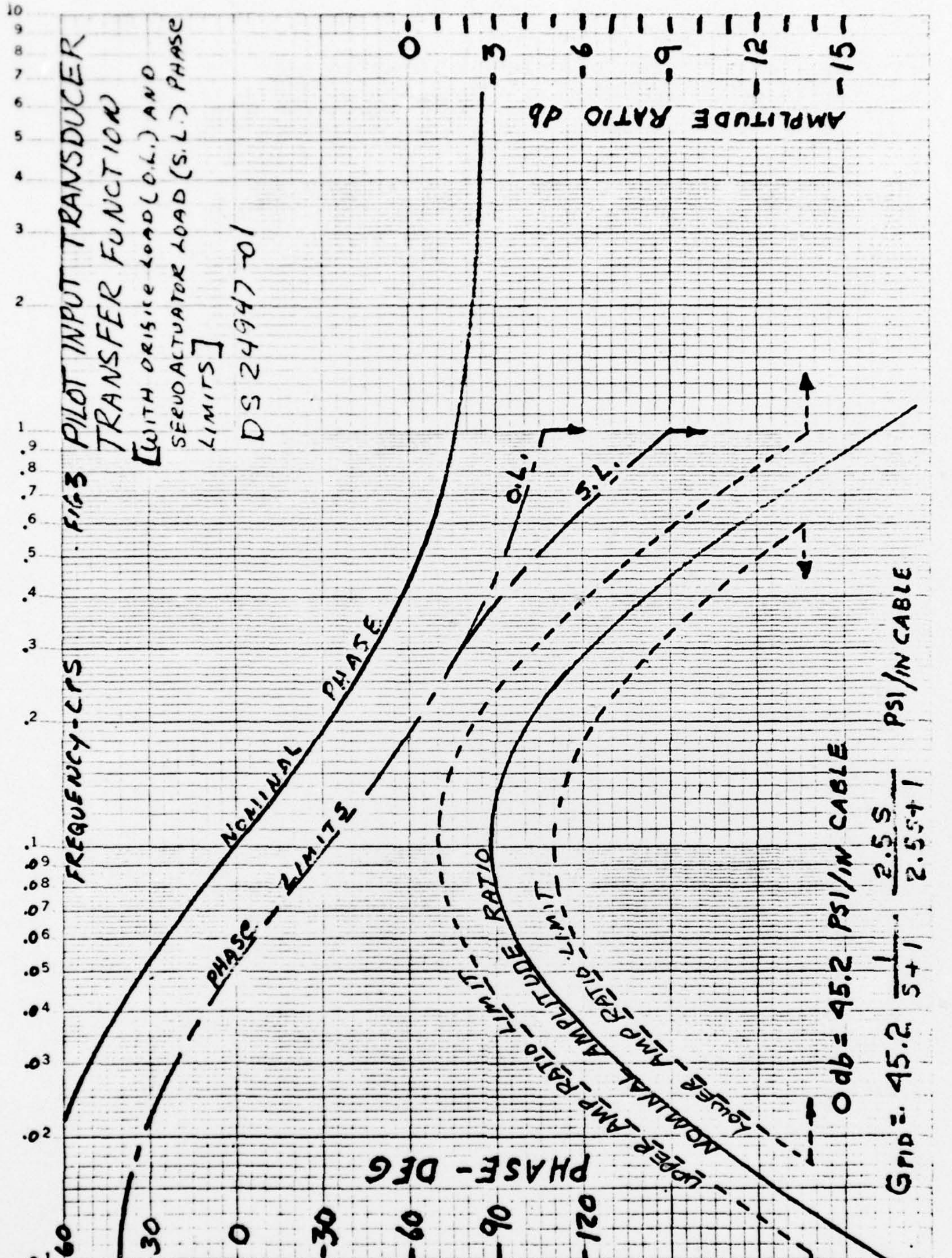


FIGURE 2
RATE TRANSFER FUNCTION
DS24947-01
FREQUENCY-CPS
NOMINAL AMPLITUDE RATIO
AMPLITUDE RATIO-db
NOMINAL PHASE
ORIFICE LOAD (O.L.)
NOMINAL PHASE
SERVOACTUATOR LOAD (S.L.)
PHASE LIM O.L.
PHASE LIM S.L.
AMPLITUDE RATIO LIMITS
PHASE DEG
0db = 0.162 PSI/°/sec
$G_R = \left[0.135\left(\frac{2.5S}{2.5S+1}\right)+0.027\right]e^{-.06S}$ PSI/DEG/SEC
6-7-76



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